Learning from an Expert Teacher: Feynman's Teaching of Gravitation as an Examplar

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Abstract: An expert teachers' instruction can be helpful to other teachers because good teaching effectively guides students to develop meaningful learning. Feynman is an excellent physics lecturer as well as one of the greatest physicists of the 20th century who presented and explained physics with his unique teaching style based on his great store of knowledge. However, it is not easy to capture and visualize teaching because it is not only the complex phenomena interrelated to various factors with the content to be taught but also the tacit representation. In this study, the framework of knowledge & belief based on the integrated mental model theory was used as a tool to capture and visualize complex and tacit representation of Feynman's teaching of 'The theory of gravitation,' a chapter in The Feynman Lectures on Physics. Feynman's teaching was found to go beyond the transmission of physics concepts by showing that components of the framework of knowledge & belief were effectively intertwined and integrated in his teaching and the storyline was well-organized. On the basis of these discussions, the implications of Feynman's teaching analyzed within the framework of knowledge & belief for physics teacher education are derived. Finally, the characteristics of the framework of knowledge & belief as tools for the analysis of teaching are presented.

keywords: Feynman, gravitation, framework of knowledge & belief, teaching physics

Ⅰ. Introduction

The teacher constitutes an important part of instruction because various educational factors such as curriculum and instructional materials are translated to students through the lens of teachers in the classroom. Armed with a growing awareness of the importance of the teacher, many studies on the teachers' role in the classroom have been initiated. Among them, researchers have shown that teachers' subject matter knowledge influences their teaching practices (Cochran & Jones, 1998; Hauslein, Good & Cummins, 1992). Shulman (1986, 1987) called attention to researchers on the importance of teachers' understanding of content knowledge. He also noted that teaching techniques used in the classroom are related to the teachers' content knowledge and are influenced by their personal understanding of the topic to be taught. Similarly, Rollnick *et al.* (2008) emphasized the importance of subject matter knowledge (SMK) as a component of PCK (Pedagogical Content Knowledge) or as a distinct area, claiming that SMK was crucial to the development of PCK per se for effective teaching. Arzi & White (2008) also

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insisted, with support from their 17-year longitudinal data, that teacher knowledge of subject matter indeed mattered. In this context, teachers' content knowledge has been a particularly important issue in science education.

The activated content knowledge of teachers for teaching is different from their content knowledge stored in their long-term memory because teaching means that teachers express their activated knowledge within the relationships among various factors in their classes. To examine how teachers express their content knowledge in the classroom is more suitable for seeing teachers' teaching rather than to investigate only teachers' content knowledge in their long-term memory. However, there are few studies that investigate teachers' subject matter knowledge activated in the process of teaching. Moreover, subject matter knowledge by itself is an insufficient condition for effective instruction although it is the first necessity because there are various factors that influence teachers' teaching besides teachers' content knowledge. According to Gess-Newsome (1999), teachers need to understand the structure and nature of their discipline, have skill in selecting and translating essential content into meaningful learning activities, maintain fluency in the discourse of the community, and recognize and highlight the applications of the field to the lives of their students. Thus, a framework is needed that enables researchers to view teacher's teaching holistically with factors related to teaching. Consequently, with this framework, it will be useful to examine how teacher's knowledge and other factors are combined to produce what happens in the classroom rather than to only investigate what teachers know about the underlying content knowledge.

Lee (2007) suggests 'the framework of knowledge & belief' on the basis of research about students' difficulties of physics learning caused by various factors. Originally, this framework was developed as an analysis tool that enables physics educators to understand causes of students' difficulties and to lead physics educators to a better understanding of choice among teaching strategies to help their students solve learning difficulties. He also suggested that this framework could be used as a tool for analyzing classes or organizing the teaching content for classes because this framework has the merit to present the relationships among components of this framework systematically. Furthermore, this framework can be used as the tool for 'seeing' teacher's teaching holistically. The results of analyzing teacher's teaching using this framework can provide an explication of the 'what' to teach as well as 'how' to teach. Especially, if expertise of teaching can be captured and portrayed within the framework of knowledge & belief, it may then be passed on to inexperienced teachers and thus assist them in their progress toward enhanced competence in teaching.

Although scientists are experts in the area of scientific knowledge related to their research, they are rarely called upon to develop and apply such explanatory flexibility – unlike experienced teachers who tailor their explanations to their students in every class. However, one scientist who explicitly made science concepts accessible to his students was Richard Feynman (Treagust &

Harrison, 2000). Feynman was well known for not only being one of the greatest physicists of the 20th century but also for being an excellent physics lecturer. He was recognized as being an effective educator for increasing understanding of physics in the public arena and in 1972 was granted the Oersted Medal for his teaching by the American Association of Physics Teachers. Goodstein & Neugebauer (1989) also stated "Feynman was more than a great teacher. His gift was that he was an extraordinary teacher of teachers." Meanwhile, Feynman gave lectures that were part of a program for developing a new course at Caltech that would introduce incoming students to many of the key ideas of 20th century physics (Sands, 2005). These lectures were transcribed as a three-volume set of books The Feynman Lectures on Physics (Feynman, Leighton & Sands, 1963) in which Feynman's effective classroom style remains intact. Among chapters in The Feynman Lectures on Physics, 'The theory of gravitation' is a typical chapter reflecting his unique teaching with a non-traditional non-geometric approach. At the same time, this is one of chapters of Six Easy Pieces (Feynman, 1995).

This present study explores and visualizes Feynman's teaching of gravitation via the framework of knowledge & belief based on the chapter 'The theory of gravitation' in The Feynman Lectures on Physics. After introducing what are considered to be the components of the framework of the knowledge & belief as one of the methods for capturing and visualizing a teacher's teaching, we discuss the characteristics of Feynman's teaching that are analyzed and visualized within the framework of knowledge & belief.

Ⅱ. A Framework of Knowledge & Belief as the tool of capturing and visualizing teaching

Early research on teachers focused attention on teacher behavior rather than teacher thinking. Later, cognitive approaches to the study of teaching and the domain-specificity of clinical problem solving led researchers to focus on teacher's thinking in content specific domains (Shulman, 1999). In this context, research on teachers' professional knowledge has expanded since Shulman published the paper that coined the phrase 'pedagogical content knowledge' (PCK) to describe the knowledge that teachers create by transforming their content into a teachable form (Rollnick *et al.*, 2008). Many researchers in the area of teacher education have recognized PCK as a critical component of the professional status of teachers (Lee & Luft, 2008). Although they have conceptualized PCK differently (Lee & Luft, 2008) since the term PCK was introduced, researchers generally agree that PCK is the amalgam of teachers' pedagogy and understanding of (science) content such that it influences their teaching in ways that will best engender students' science learning for understanding (Loughran, Mulhall & Berry, 2004). However, because most of the research on PCK is mainly focused on teachers' knowledge and does not consider other factors that influence their teaching, these researchers cannot show the big picture of teaching. Concretely, science educators have become aware of the possible impacts of teachers' beliefs about the nature of science on their instructional

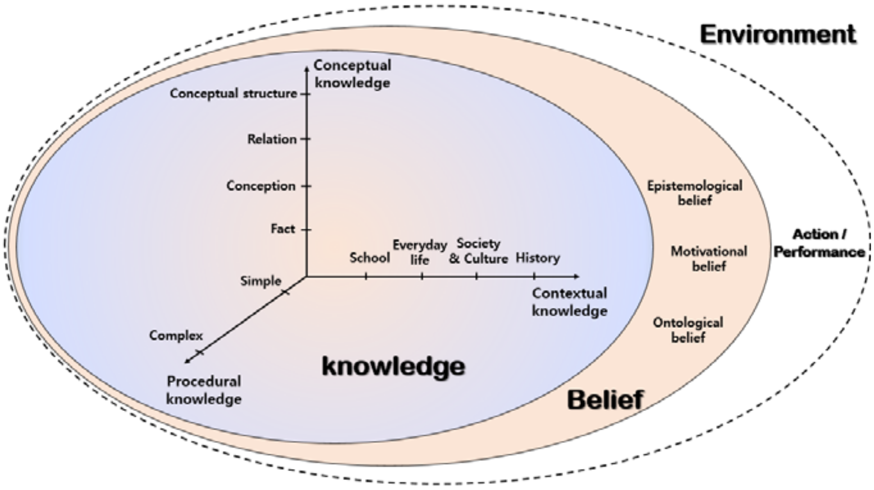

Figure 1. The framework of knowledge & belief (Adapted from Lee, 2007)

plans and teaching practice (Abd-El-Khalick, Bell & Lederman, 1998; Lederman, 1992, 1999; Tsai, 2002). In other words, teachers' actions are guided by and make sense in relation to their personally held system of beliefs (Haney *et al.*, 2002; Pajares, 1992). Yilmaz-Tuzun & Topcu (2008) also argue in a study of preservice elementary science teachers that teachers' epistemological beliefs certainly affect the way they teach. In light of these researches, because teachers' belief is one of the influential factors of impacting teaching, we have to consider teachers' beliefs with their knowledge when we observe their teaching in classes. Teachers' working knowledge is also as much dependent on the environment within which teachers work as on the individuals because such knowledge exists within various systems - cultural, physical, social, historical, and personal - and that learning to teach involves developing ways of interacting within these systems (Calderhead, 1996). Thus, researchers who want to see 'teaching' holistically related to learning should consider teacher's knowledge activated in his/her class in the relationships among the teacher's belief, action/performance, and environment.

However, it is difficult to find suitable tools for investigating teacher's teaching holistically. Although CoRe (Content Representation) which represents the particular content/topic of the science teaching and Pap-eRs (Pedagogical and Professional experience Repertoires) which help to illuminate specific aspects of the CoRe (Loughran, Mulhall & Berry, 2001) are mainly used to investigate PCK, both forms of representation of teachers' PCK are limited in that they do not enable us to 'see' the teaching in action, or tell us how teachers' beliefs about the nature of the knowledge represented influences their practice (Mulhall, Berry & Loughran, 2003).

Recently, the framework of knowledge & belief (Figure 1) based on the integrated mental model theory that describes holistically the processes of students' learning in terms of mental models is suggested (Lee, 2007). By the integrated mental model theory (Lee *et al.*, 2005), information about a science concept and problem that catches students' attention through sensory memory is activated in working memory. At the same time, students' knowledge and beliefs in long-term memory related to the problem usually are activated in working memory. Mental representations formed by their interactions are mental models demonstrated by expressed models (e.g. drawings or words). Lee (2007) categorized various factors that influence the processes of forming mental models into four types - knowledge (conceptual, contextual, procedural), belief (epistemological, ontological, motivational), action/performance, and environment and named it 'the framework of knowledge & belief'. The reason for the name of this tool is that, though the processes of forming mental models are clearly affected by factors related to the environment and action/performance, the importance of knowledge and belief in the processes of students' thinking or learning needs to be emphasized. He also showed in this article the relationship between the integrated mental model theory and categorized factors (knowledge, belief, action/performance, and environment) that affect the processes of forming mental models through an analysis of high school student's difficulties about circular motion.

Although this integrated mental model theory is suggested to explain the process of students' learning, it can also explain teachers' knowledge and beliefs represented in their classes with expressed models from the aspect of forming and representing knowledge and beliefs on the specific teaching context. Concretely, 'the situation of preparing lessons' is an 'event' in teacher's work. In the situation, one part of the knowledge and belief in long-term memory of teachers is activated, and activated knowledge is reconstructed and represented by the interaction with the situation of the real class and the content. According to this theory, teaching in the specific class is based on activated knowledge. To investigate and understand the teacher's teaching holistically, we need to examine how a teacher's knowledge is represented in any environment considering other factors related to teaching and the relationships among these factors. In this context, the framework of knowledge & belief based on the integrated mental model theory has more utility in capturing and visualizing teacher's teaching.

The purpose of this study is to draw implications that can contribute to physics teacher education derived from an analysis of Feynman's teaching within the framework of knowledge & belief. However, we cannot observe his teaching directly because he passed away in 1988. Instead, we can investigate his activated knowledge considering other factors through his books where his teaching is described and then analyze characteristics of his teaching from them. As noted by Shavelson (1974, p. 232), "A structure of a subject matter, ultimately, rests in the minds of the 'great scientists.' This structure is communicated through the scientists' writings in journals and advanced textbooks as well as through informal communication channels." Moreover, because The Feynman Lectures on Physics were written based on lectures for the introductory physics classes at Caltech, these books can provide a unique glimpse into the teaching of Feynman. Thus, in this study we captured and visualized Feynman's teaching with a focus on the specific knowledge of 'Gravitation' considering what and how other factors influence the activating of Feynman's subject matter knowledge related to gravitation.

Ⅲ. Research Context

1. Research method

The research method used in this study is a case study to systematically look at a specific event (Anderson,2000) - Feynman's teaching of 'Gravitation'. Especially, the purpose of this study is to capture and visualize Feynman's teaching, to derive implication for physics teacher education, and to investigate how the framework of knowledge & belief can be used as a tool for analyzing teacher's teaching.

Table 1. Explanation on the components of the framework of knowledge & belief (Adapted from Kim, Lee & KLOPE, 2007)

Component		Explanation
Knowledge	Conceptual knowledge	· Knowledge related with concept · Elements: [Fact], [Conception], [Relation], [Conceptual structure]
	Procedural knowledge	· Knowledge related with a process of making use of information and ability for learning science · Elements: e.g. Orderly thinking (Donald, 2002)
	Contextual knowledge	· Knowledge related with a use of specific knowledge in specific context · Elements: [School], [Everyday life], [Society & Culture], [History]
Belief	Epistemological belief	· Belief about knowing and learning that play a mediating role in the processing of the information · Belief about what constitutes knowledge in physics and how a person develops that knowledge
	Ontological belief	· Belief about the kinds of entities we assume to exist and the way they are categorized
	Motivational belief	· Belief about teaching and learning · Goal orientation, interest/value, efficacy, control belief etc.
Action / Performance		· Action/Performance related to teaching · Elements: e.g. teaching strategies, teaching model, teaching sequences
Environment		· The back ground which affects one's knowledge & belief, or is affected by them. · Environment of teacher: physics, (atmosphere of) classroom, students, instructional materials, peer teachers, university entrance examination system, society etc.

The Feynman Lectures on Physics, transcriptions of lectures in a two-year introductory physics course given in the early 1960s by Feynman at Caltech, provide us with a complete description of Feynman's actual teaching. One chapter in the book, 'The theory of gravitation', was analyzed and visualized through the framework of knowledge & belief (Figure 1, and Table 1) in this study in order to describe Feynman's teaching holistically. Table 1 contains an explanation about how the components of the framework of knowledge & belief were elaborated based on the previous work of Lee (2007) and Lee & Kim (2008). For example, it includes the factor 'Action/ Performance' that the previous version of figures presented at the Physics Education Research Conference (2008) did not explain. The explanations are changed slightly to be suitable for research on teaching. We inferred the factor 'Environment' that influenced Feynman's teaching about 'Gravitation' by analyzing several articles that gave information about Feynman's teaching, including Feynman's preface (Feynman, 1963) of The Feynman Lectures on Physics, Introduction (Davies, 1994) and Special Preface (Goodstein & Neugebauer, 1989) of Six Easy Pieces (Feynman, 1995), and Capturing the wisdom of Feynman (Sands, 2005) because we could not directly investigate this factor 'Environment' in the chapter 'The theory of gravitation'.

Concretely, there are three kinds of knowledge - conceptual, procedural, and contextual knowledge. Though this knowledge was mostly developed with reference to science content, the knowledge in the framework does not need to be limited to the subject matter content. If it means observable and activated knowledge, components of the knowledge in the framework imply conceptual, procedural, and contextual knowledge as an aspect of science education, namely, science teaching. Each form of knowledge has subcomponents. For example, conceptual knowledge is composed of facts, conceptions, relationships and a conceptual structure. Contextual knowledge is related to a use of a specific knowledge in specific contexts such as school, everyday life, society & culture, and historical context. Procedural knowledge is related to a process of making use of information and ability for teaching science. Namely, to teach this knowledge means to facilitate students to think their way through the subject matter. Sub-items of this knowledge depend on aspects emphasized in teaching. In this study, the procedural knowledge is composed of description, local inference, comparative thinking, and open investigation.

Belief is located between knowledge and environment because belief is the connection which links our knowledge and life. This belief acts as an information filter and impacts how knowledge is used, organized and retrieved. Concretely, epistemological belief is a belief about knowing and learning that plays a mediating role in the processing of the information and about what constitutes knowledge in physics and how a person develops that knowledge. Ontological belief is a belief about the kinds of entities we assume to exist and the way they are categorized. Motivational belief is belief about teaching and learning such as goal orientation, interest/values, efficacy, and control belief and so on.

Action/performance is defined as the result of the interaction among individual knowledge, belief and environment like teaching strategies when this tool is used for capturing teaching. In Figure 1, the boundary between action/ performance and environment is expressed by a dotted line, not a complete line because we want to emphasize that action/performance is the result of the interaction among knowledge, belief and environment. Meanwhile, teaching is teacher's action in the class which needs to be distinguished with the factor 'Action/ Performance' in the framework of knowledge & belief. We limited the factor 'Action/ Performance' in this framework to characteristics of teachers' activities in the class inferred by researchers.

Environment is the background which affects one's knowledge, belief and action or is affected by them. When this framework is used as the tool for investigating teachers' teaching, there are many components of the teaching environment – the teaching subject (physics), (atmosphere of) the classroom, teaching materials, tests, curriculum, university entrance examination system, and physical environment like equipment, society, etc.

2. Research procedure

The following procedure was used to establish the reliability and validity of this study. In the first stage, the first and second authors discussed and practiced this framework of knowledge & belief with the topic of circular motion in a secondary physics classroom (Park & Lee, 2008). In the second stage, the second and third authors analyzed the chapter 'The theory of gravitation' of The Feynman Lectures on Physics with this framework based on the experience gained in the first stage. The researchers tried to interpret a teacher's real teaching in a class with their theoretical lens. Thus, their interpretation was not real phenomena, but reconstructed phenomena from the perspective of the specific theory (Figure 2). In this stage, the authors used the two steps shown in Figure 2 when they captured and visualized Feynman's teaching of 'Gravitation' within the framework. In the third stage, the first, second, third authors and other laboratory members discussed the results of the second stage to elaborate them. In this stage, each evaluator explained the points of disagreement and, after some discussion, consensus was achieved. At the fourth stage, the results of the third stage were presented at the Physics Education Research Conference (2008), ICSENS (International Conference on Science Education for Next Society, 2007) and 2007 KPS fall conference and modified based on feedback. In the fifth stage, the first, second and fourth authors in this study elaborated and developed the results of the fourth stage.

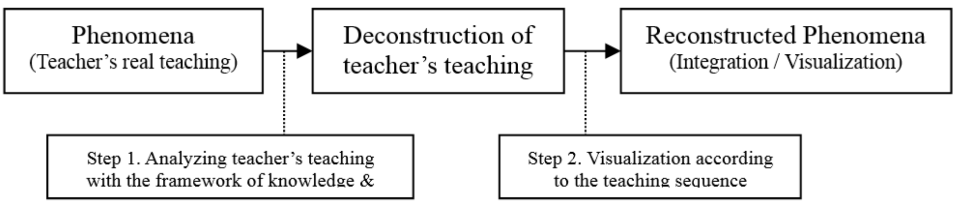

Figure 2. Steps of capturing and visualizing Feynman's teaching of gravitation

Ⅳ. Results

1. Capturing Feynman's teaching of gravitation analyzed via the framework of knowledge & belief

Feynman's teaching of gravitation represented in his class through the framework of knowledge & belief is summarized in Table 2.

Feynman introduced conceptual knowledge in the order of facts related to gravitation, the concept of gravitation, and the relation of gravitation to other theories. This order had a tendency that was toward organized conceptual knowledge. His teaching is unique in that he used a variety of contextual knowledge rather than mathematical calculations to provide a guide and a crutch to take readers into unfamiliar territory compared to most theoretical physicists (Davies, 1994). Especially, he taught students gravitation based on the historical background. Concretely, Feynman focused on the historical background of the theory of gravitation, the process of inferring gravitation from Newton's laws of motion, applications of gravitation, and relationship of Newton's law of gravitation to Einstein's theory of relativity. This was deeply connected to the contextual knowledge as shown in Table 2. With the knowledge in historical contexts, Feynman explained how the law of gravitation applied to universal phenomena and affected social and cultural contexts. Besides, he introduced the concept of gravitation and represented mysteries of gravitation. In the case of the procedural knowledge, he introduced it from simple to complex form; description, logical inference, comparative thinking, and open investigation. At first, he described the law of gravitation in the mathematical form and the historical background of the theory of gravitation including the ancients, Copernicus, Brahe, and Kepler. After then, he inferred logically the law of gravitation from Kepler's third law and Newton's laws of motion, and explained logically the motion of the moon, tidal effect, shape of the earth etc. using the concept of gravitation. Next, he presented mysteries about the machinery of gravitation and about the relative strengths of the electric force and the gravitational force. In the process of connecting Newton's theory of gravitation with Einstein's theory of relativity, he used 'Comparative thinking'. Finally, he finished this chapter by referring to future directions of physics related to gravitation based on the consistency of physical theories.

Next, the most obvious aspect among Feynman's beliefs represented in this chapter is the epistemological belief as shown in Table 2. This aspect also was referred to by Davies (1994) who placed a high valuation on Feynman's ability to develop a deep theoretical understanding of nature, but always to remain close to the real and often grubby world of experimental results. This was also shown in section 7-4 as follows; "Any great discovery of a new law is useful only if we can take more out than we put in." (p. 7-4). In section 7-8, he also emphasized the consistency of physical theories. Through this aspect, we assumed that he had belief about the structure of physics knowledge as a single coherent system. Moreover, his motivational belief

Table 2. The characteristics of Feynman's teaching of gravitation (Adapted from Kim, Lee & KLOPE, 2007)

Section	Knowledge			Belief	Action / Performance [Teaching sequence]	Environment
	Conceptual	Contextual	Procedural			
7-1. Planetary motions	① Gravitation	School context	Description	<Motivational belief>	[Introduction]	• Physical context of these lectures: The big lecture room (Feynman, 1963) • The intended audience ① Undergraduate (freshman and sophomore) students at Caltech (Davies, 1994; Goodstein & Neugebauer, 1989) ② The whole group of 180 students (Feynman, 1963) • Context of Feynman's lectures : The part of a program for developing a new course that would introduce incoming students to many of the key ideas of 20 th-century physics (Sands, 2005)
7-2. Kepler's laws	② Planetary motions & Kepler's laws	Historical context : ancients - Copernicus - Brahe - Kepler	Description	<Epistemological belief> : Experimentalism	[Concept introduction]	
7-3. Development of dynamics	③ Newton's law of motion	Historical context : Galileo - Newton	Logical inference			
7-4. Newton's law of gravitation	④ Newton's law of gravitation	Historical context : Newton	Logical inference			
	⑤ Application of gravitation	Social and Cultural context (Usefulness of gravitation) + Historical context	Logical inference	<Epistemological belief> : Useful law	[Concept application]	
7-5. Universal gravitation				<Epistemological belief> : Falsification		
7-6. Cavendish's experiment		Historical context : Cavendish		<Epistemological belief> : Useful law		
7-7. What is gravity?	⑥ Mysteries of gravitation	School context + Historical context	Open investigation	<Epistemological belief> : Characteristics of physical laws <Epistemological belief> : Nature of science		
7-8. Gravity and relativity	⑦ Gravity and relativity	Historical context : Newton - Einstein	Comparative thinking			
	⑧ Relationships of gravitation to the other theories	Social and Cultural context (Future direction of physics)	Open investigation	<Epistemological belief> : Consistency in physical theories		

about the theory of gravitation can be expressed in the introduction phase; "In this chapter we shall discuss one of the most far-reaching generalizations of the human mind." (p. 7-1). Another characteristic of Feynman's lecture about 'Gravitation' is that the teaching sequence follows three phases. In the introduction phase, Feynman tried to make students focus their attention on the topic 'Gravitation', and inform them about the lecture's objectives. In the concept introduction phase, he introduced the law of gravitation in the historical context. Moreover, he inferred logically the law of gravitation from Kepler's third law and Newton's laws of motion. In the concept application phase, he challenged and extended students' understanding of gravitation. Through new experience like universal phenomena, he gave his audience opportunities to develop a broader understanding. Besides, he led his audience to a deeper understanding by connecting Newton's gravitation with a new theory like Einstein's theory of relativity and stimulated their intellectual curiosity about physics theories like gravitation. This aspect is related to the purpose of Feynman's lectures as mentioned in 'Environment' of Table 2.

2. Visualizing Feynman's teaching of gravitation analyzed via the framework of knowledge & belief

The deconstructed teaching of Feynman with factors of the framework of knowledge & belief was reconstructed with Figure 1 to visualize his teaching holistically. This section shows results of visualizations of Feynman's teaching of gravitation according to the teaching sequence based on results of the previous section (Table 2). Thus, we did not include 'Action/Performance' in the figures below within this section. Also, we described Feynman's teaching focused on activated subject matter knowledge within the relationships of factors in the framework of knowledge & belief. Concretely, Figure 1 is a three dimensional Cartesian coordinate system, with axes - Conceptual knowledge, Procedural knowledge, and Contextual knowledge. The marks on the axes are decided according to orientations for axes; Conceptual knowledge (Fact, Conception, Relation, Conceptual structure), Procedural knowledge (Description, Logical inference, Comparative thinking, Open investigation), and Contextual knowledge (School, Everyday life, Society & Culture, History) based on the results presented in the previous section. Activated subject matter knowledge was expressed as the point where three lines drawn perpendicularly from each axis meet according to the activated order. And factors such as belief and environment that influence activating knowledge also were described to show Feynman's teaching holistically.

1) Introduction

In the introduction phase, Feynman started his teaching by motivating his students to understand the importance of gravitation theory as follows, "In this chapter, we shall discuss one of the most far-reaching generalizations of the human mind. While we are admiring the human mind, we should

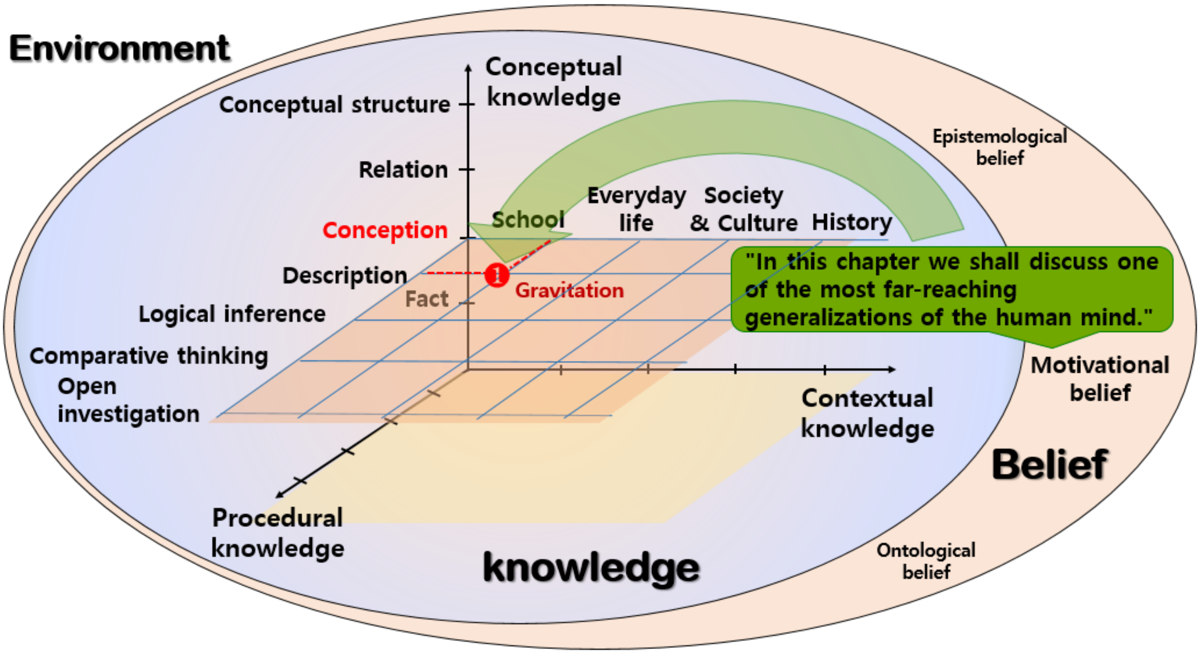

Figure 3. Visualization of Feynman's teaching of gravitation in the introduction phase

take some time off to stand in awe of a nature that could follow with such completeness and generality such an elegantly simple principle as the law of gravitation." (p. 7-1) After that, he defined and expressed the law of gravitation in the mathematical form at an introductory level (① in Figure 3).

2) Concept introduction

In the concept introduction phase, Feynman described facts about planetary motions & Kepler's laws and Newton's laws of motion in a historical context (②, ③ in Figure 4).

In this phase, sympathizing with Brache's idea that the motion of planets could be proved from the measurement, Feynman said "This was a tremendous idea — that to find something out, it is better to perform some careful experiments than to carry on deep philosophical arguments." (p. 7-1). From this part, when he taught 'Planetary motions & Kepler's laws' to students, we identified that his epistemological belief like experimentalism influenced his teaching. After that, he inferred logically the law of gravitation from these laws as identified in his words "From his better understanding of the theory of motion, Newton appreciated that the sun could be the seat or organization of forces that govern the motion of the planets. … Next, by analyzing Kepler's third law it is possible to show that the farther away the planet, the weaker the forces. … With the combination of the two laws, Newton concluded that there must be a force, inversely as the square of the distance, directed in a line between the two objects." (p. 7-3) (④ in Figure 4).

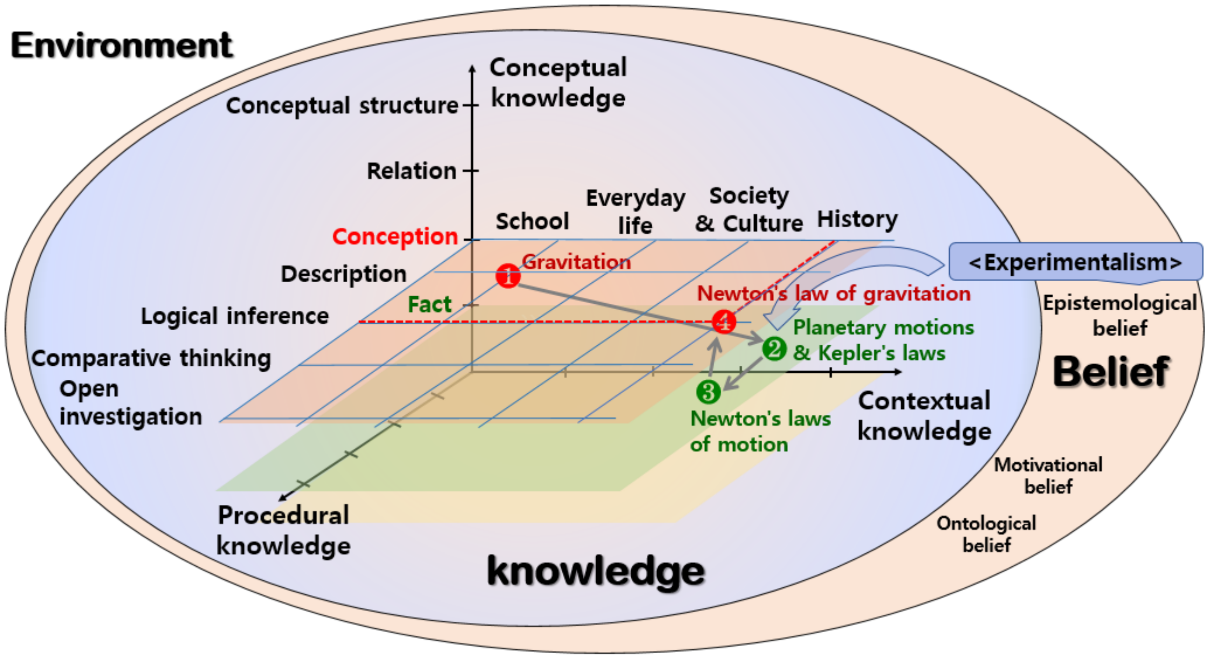

Figure 4. Visualization of Feynman's teaching of gravitation in the concept introduction phase

3) Concept application

In the concept application phase, by introducing the law of gravitation in the social and cultural contexts as well as the historical context, he tried to make students elaborate the concept of 'Gravitation' deeply. Concretely, in this phase, the application of gravitation (⑤ in Figure 5), mysteries of gravitation (⑥ in Figure 5), gravity and relativity (⑦ in Figure 5), and relationships of gravitation to the other theories (⑧ in Figure 5) were activated as central conceptual knowledge.

When Feynman activated 'Application of gravitation' (⑤ in Figure 5) in his class, the concept of gravitation was interconnected through his procedural knowledge that allowed explanation about the contextual knowledge that was related to universal phenomena such as the motion of the moon, tidal effect, galaxy, origin of the stars and so on. Through his words "Any great discovery of a new law is useful only if we can take more out than we put in." (p. 7-4), we identified that epistemological belief like 'Useful law' influenced the activation of 'Applications of gravitation' (⑤ in Figure 5). Besides, when he explained motion of the moons of Jupiter in section 7-5 with the question "What else can you do with the law of gravitation?" (p. 7-5) as one of applications of gravitation, the completeness or generality of the law of gravitation was emphasized through 'Falsificationism' as shown in his words "If a law does not work even in one place where it ought to, it is just wrong." (p. 7-5). Afterwards,

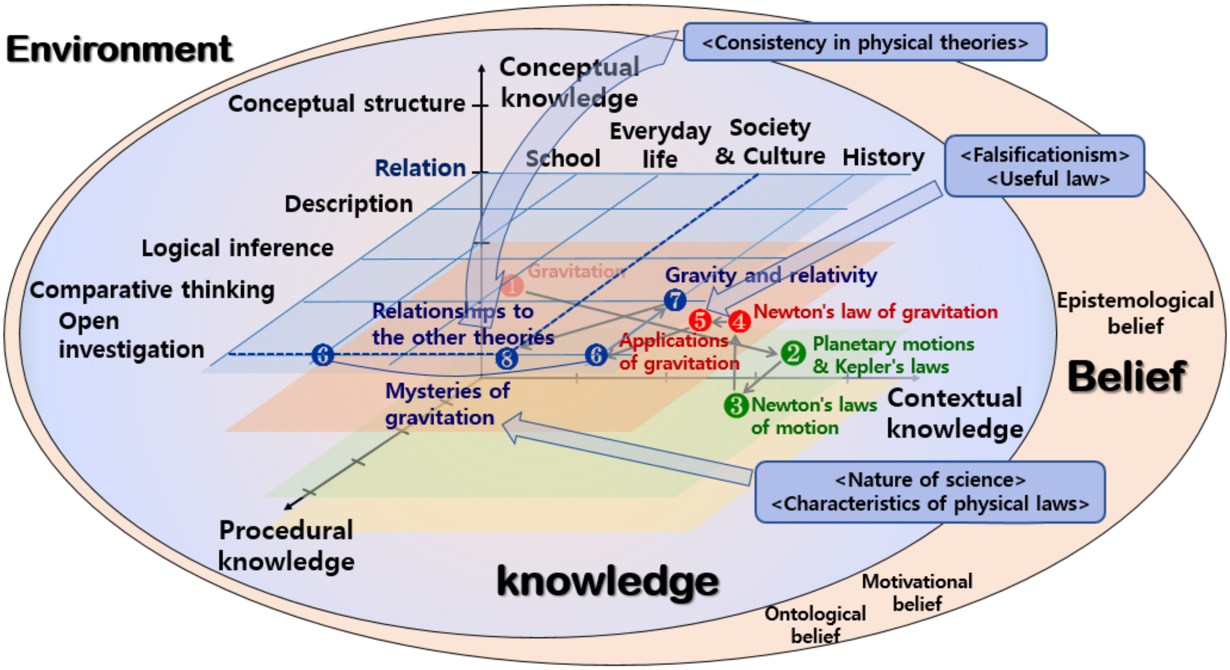

Figure 5. Visualization of Feynman's teaching of gravitation in the concept application phase

when he introduced Cavendish's experiment in a historical context, he stated that "… this fact that all the moons and planets and stars have such a simple rule to govern them, and further that man could understand it and deduce how the planets should move! This is the reason for the success of the sciences in the following years, for it gave hope that the other phenomena of the world might also have such beautifully simple laws." (p. 7-9) From these sentences, it seemed that epistemological belief like 'Useful law' influenced his activated conceptual knowledge 'Applications of gravitation' (⑤ in Figure 5).

Feynman led students to open investigations on unsolved problems related to gravitation (⑥ in Figure 5) with epistemological questions and views related to 'Characteristics of physical laws', "But is this such a simple law? What about the machinery of it? All we have done is to describe how the earth moves around the sun, but we have not said what makes it go. … No one has since given any machinery. It is characteristic of the physical laws that they have this abstract character. … Why can we use mathematics to describe nature without a mechanism behind it? No one knows. We have to keep going because we find out more that way." (p. 7-9). Besides, he exposed 'Nature of science' as the epistemological belief in his words "We have to keep going because we find out more that way." (p. 7-9). Next, Feynman compared Newton's theory of gravitation with Einstein's theory of relativity by activating 'Comparative thinking' as procedural knowledge (⑦ in Figure 5). Concretely, he explained why Newton's theory of gravitation should be modified by Einstein's theory of relativity by pointing out the weakness of gravitation theory, "Einstein advanced arguments which suggest that we cannot send signals faster than the speed of light, so the law of gravitation must be wrong. By correcting it to take the delays into account, we have a new law, called Einstein's law of gravitation." (p. 7-11)

Finally, he showed the relationships of gravitation to the other theories like relativity and quantum mechanics (⑧ in Figure 5). He also presented some of the problems of gravitation theory to be solved and the future direction of physics in the social and cultural context based on 'Open investigation' among procedural knowledge. We can find Feynman's view, namely, epistemological belief, such as consistency in physical theories, from his explanations in this phase, "None of these nuclear or electrical forces has yet been found to explain gravitation. The quantum-mechanical aspects of nature have not yet been carried over to gravitation. …for constancy in our physical theories it would be important to see whether Newton's law modified to Einstein's law can be further modified to be consistent with the uncertainty principle. This last modification has not yet been completed." (p. 7-11)

Ⅴ. Discussion

Education is implemented by the interaction between the teacher and students in a particular environment. Etymologically, the verb "educate" is derived from educare (Latin) "bring up", which is related to educere "bring out", "bring forth what is within", "bring out potential" and ducere, "to lead" (Online etymology dictionary, 2011). This means that though the main agents of learning are students, the persons who lead students and bring out their potential are teachers. In line with this view, we need to see how expert teachers teach their students content knowledge and to find the good ways to facilitate students' learning. When researchers see teachers' teaching focused on content knowledge activated in their classes, they considered it within the interrelationship among teacher's belief, the environment where teaching occurs and action/performance. In this context, the framework of knowledge & belief based on the integrated mental model theory is a good lens for capturing and portraying teaching holistically. The analysis and visualization of teaching through the framework of knowledge & belief definitely have differences compared to previous analysis of the PCK in the light of showing teacher's teaching holistically by describing each component of the framework of knowledge & belief and the interrelationship among factors that influence teaching. Concretely, those characteristics of Feynman's teaching exposed by analyzing within the framework of knowledge & belief are as follows.

Firstly, factors that influence teaching, namely components of the framework of knowledge & belief, were effectively intertwined and well-organized in his teaching. This characteristic of his teaching enabled him to facilitate students to deeply understand other things like the nature of physics as well as content knowledge. For example, diverse contextual knowledge about gravitation in his teaching guides students to understand gravitation deeply. Among this knowledge, historical background that shows how the law and theory of physics have developed is effective in improving students' epistemological belief with their understanding of content knowledge. This shows that conceptual knowledge, contextual knowledge and epistemological belief are interconnected, and illustrates that this intertwined relationship with well-organized teaching structure can make teaching effective.

Secondly, the nature of physics was emphasized in his teaching as shown in Table 2. Concretely, the tentativeness of physics is reflected in his teaching. As mentioned above, he explained in his class how the law of gravitation developed in a historical context and described that this law is in the process of developing continually. In other words, he showed that the process of developing physics depended both on making careful observations of phenomena and on inventing theories for making sense out of those observations. Consequently, students can recognize that science is always a work in progress and its conclusions are always tentative. And, with the law of gravitation, Feynman emphasized the characteristics of physical laws, referred to a 'Useful law' in Table 2. From this aspect, we can presume that he regarded physics as a vast single system in which the basic rules are everywhere the same.

Thirdly, his lecture focused on developing a deeper understanding with diverse contextual knowledge based on procedural knowledge like logical inference and open investigation rather than mathematical forms. This characteristic is parallel to Davies's (1994) explanation that Feynman gave lectures in an idiosyncratic way that meant eschewing existing formalisms and developing his own highly intuitive approach. Through this teaching approach, Feynman facilitated his students to develop integrated and scientific conceptual structures, not fragmented facts. For example, Feynman showed that the law of gravitation applied in various contexts with logical inference and the relation of gravitation to other forces. This teaching can guide students to have beliefs about the structure of physics knowledge as a single coherent system and about the content of physics knowledge as concepts that underlie the formulas. Moreover, it facilitates students to have well-organized conceptual knowledge consisting of concepts and theories that are interconnected.

Fourthly, procedural knowledge like logical inference was emphasized in his teaching. To teach physics does not mean just to make students understand physics. Additionally, teachers have to teach thinking processes through physics. Concretely, logical inference that connects evidence and assumptions with conclusions and imagination is essential for these visualizing natural processes in the mind and to recognize the links between different pieces of information; these play an important role in the development of physics. In Feynman's teaching, we can identify his logical inference when he applied the law of gravitation in various contexts.

Fifthly, the context of the physics community at that time was reflected as one factor in the 'Environment' in his teaching. One purpose of Feynman's lectures is to introduce incoming students to many of key ideas of 20th century physics (Sand, 2005). This is shown in the process of comparing Newton's gravitation with other new theories, like relativity, in his teaching.

Through the characteristics of Feynman's teaching that are exposed by an analysis within the framework of knowledge & belief, we concur that this analysis can help physics educators plan their lectures with reference to the same topic, especially the content story line. Because the 'Environment' involving student, curriculum, and physical environment could not be analyzed from the chapters in his book, the person who prepares lectures must use and develop the result of analyzing Feynman's teaching according to his or her own instructional environment. Feynman could not consider properly the students who are one of the factors of the 'Environment'; he saw this as a difficulty as noted in the book's preface (Feynman, 1963, p. 4): "In giving these lectures there was one serious difficulty: in the way the course was given, there wasn't any feedback from the students to the lecturer to indicate how well the lectures were going over. This is indeed a very serious difficulty, and I don't know how good the lectures really are. The whole thing was essentially an experiment." Although Feynman (1963) was aiming his teaching at the more intellectually active student, many of the students dreaded the class, and as the course wore on, attendance by the registered students started dropping alarmingly. But at the same time, more and more faculty and graduate student started attending (Goodstein & Neugebauer, 1989). As shown in Feynman's preface (Feynman, 1963), he also referred to the importance of the interaction between teacher and environment, especially with students.

In summary, although Feynman did not consider the 'Student' factor thoroughly, his teaching was well balanced and organized among the physics concepts, procedural knowledge, contextual knowledge, and teachers' beliefs on physics. This is a good example of physics teaching that facilitates students to understand physics deeply and scientific epistemological beliefs in a content-oriented physics lecture. Besides, lectures are the most widely used teaching method in secondary and college/university physics classes because they are a convenient and efficient way of introducing large numbers of students to a particular field of study. However, they are much criticized at the same time. Critics point out that lecturing is mainly a one-way method of communication that does not involve significant audience participation. Because of this point, it is easy for lectures to focus on the information-transmission without improving deeper conceptual knowledge as well as scientific beliefs etc. Feynman's teaching showed the alternative that can complement the limitation of these lectures.

Ⅵ. Conclusion

While research reports that the more knowledge teachers have, the more effectively they teach the topic to students (e.g. Carlsen, 1991), knowing much is not a synonym for teaching well as shown in research that the knowledge of scientist is different from that of expert teachers. By contrast, there are characteristics of scientists and expert educator in Feynman's teaching which are evident in the results of this study analyzed within the framework of knowledge & belief. These results lead to implications on physics teacher education whose ultimate goal is to develop effective teachers, especially in preservice and novice physics teacher programs. Firstly, the result of analysis of Feynman' teaching within the framework of knowledge & belief can be a good example of lectures whose dual goals are to build subject matter knowledge of preservice or novice teachers and preparing them to teach that content. Secondly, as shown in the results of this study, Feynman emphasized contextual and procedural knowledge as well as conceptual knowledge. Thus the results of capturing and portraying Feynman's teaching within the framework of knowledge & belief can be the basis of developing a teacher educator program that emphasizes two purposes of physics teaching - process and content. Thirdly, to understand physics requires scientific epistemological belief. However, it is difficult to teach this belief by referring to the classroom. Because of this point, preservice and novice teachers have difficulties in facilitating their students to improve this epistemological belief. Feynman's teaching shows the way for teaching scientific epistemological beliefs with the content of gravitation. Fourthly, the results presented in this study can be a good example that shows how teachers or lecturers can teach beyond the physics content by using the history of physics in lectures to guide students to understand physics deeply. In brief, the main purpose of this study was to contribute to physics teacher education by drawing instructional implications from the interpretation of Feynman's teaching about "Gravitation" using the framework of knowledge & belief. The purpose was not to describe all aspects of his lecture. Further research issues stem from this study. We need to continue the study on Feynman's teaching by analyzing more chapters from The Feynman Lectures on Physics as well as other resources (voice-recorded files, other books written by Feynman). Based on these studies, we can build well-structured physics content storylines for teaching physics and learn how to build subject-oriented PCK for teaching specific physics content.

We also identify how this framework is an effective lens for seeing 'teaching' holistically in this study and derive the general contributions of the framework of knowledge & belief in teacher education. Firstly, the data analyzed and visualized within this framework can help teachers plan the content of the same topics which teachers can modify to be suitable to their particular environment. Secondly, in research on teaching that has tacit, complex, and individual characteristics, the data analyzed and visualized within the framework of knowledge & belief can be used to develop programs for preservice teachers and beginning teachers. Concretely, if the analysis and visualization with this framework are used in the program for teacher education, it can look beyond simply gathering up 'activities that work' and move beyond seeking good activities and teaching content and pedagogy separately. Thirdly, this framework can be used as a tool for teachers' self-reflection. By seeing the results revealed through this framework, teachers can recognize which parts they should modify or reinforce. Fourthly, expert teachers' teaching accumulated within this framework can be based on developing effective teaching strategies for solving students' difficulties about learning physics. In conclusion, the framework of knowledge & belief is not only a good tool for analyzing and visualizing teaching but also is valuable in teacher education.

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