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The Effect of Guided Inquiry Laboratory on Conceptual Understanding

Miha Lee

California State University, Northridge

ABSTRACT

This study examined how students' conceptual understanding developed with inquiry laboratory activities and assessed the contribution of inquiry laboratory to conceptual understanding. Participants included 158 Korean students in Grade 11. The subject and the unit were Chemistry I and Metal. In instruction students were given well-structured laboratory work sheets and asked to conduct chemistry experiments, analyze their data and then draw conclusions with regard to the driving question and the subquestions. A pretest, four formative tests, a delayed posttest a students' survey were administered. A variety of learning paths were revealed. However, a major learning path from preconceptions (big four concepts about metals' physical properties) to target concepts (big three concepts about metals' chemical properties) was identified. Students' learning process seems to have been changed from direct assimilation to conceptual change as learning activities were progressed. Students proved to achieve well factual knowledge which are required elements of the intended conceptual structure from the inquiry laboratory. However, the overall efficiency of inquiry laboratory for conceptual understanding was lower than expected because majority of the students failed to build the well organized conceptual structure under an overarching concept. The implications,

limitations and recommendations were described.

The Effect of Guided Inquiry Laboratory on Conceptual Understanding

Advancement of science and technology has been so rapid that currently useful knowledge can become obsolete in a short period of time. However, the results from the National Assessment of Educational Progress [NAEP] (see also the website http://www.nagb.org/) showed that most students could recall simple science facts, but that they lacked of higher levels of scientific literacy. Students were weak in applying the facts they knew, interpreting data, evaluating experimental design, and using specialized scientific knowledge to draw conclusions. In other words, they were poor at reasoning scientifically, which means they don't really understand science (Bruer, 1994). As a result, concerns about the educational demands of the 21st century inspired an intensive claim of education reform in 1990s. Such educational reform efforts have required a shift in the emphasis of science education from memorization of facts and procedures to a deeper understanding of the subject matter (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; NRC, 2005). Thus, the National Science Education Standards of the United States was released, calling for inquiry as a way in which "students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills" (NRC, 1996, p. 2). Recommendations for improved teaching of science are solidly rooted in a commitment to teaching both through and about inquiry (Crawford, 2000; NRC, 1996; NRC, 2000; NRC, 2005).

In Korea, the Ministry of Education formed the Education Reform Committee in 1994, and released the 7th National Curriculum which has been implemented since 2000 (Ministry of Education & Human Resources Development [MoE], 1999). In 2007, the revised 7th National Curriculum was announced and will be put into practice from the 2009 academic year (MoE, 2007). The Curriculums placed a higher emphasis on the science education for the sake of our nation's human resource development (MoE, 2007) because the number of high school students who pursue science and technology has plunged (Ministry of Science and Technology, 2002; Oh, 2002). The main goal of these Curriculums in high school science education is that students should appreciate the nature of science, understand scientific knowledge system, and develop the ability of inquiry (MoE, 2007). In accordance with MoE's educational reform efforts, the Seoul Metropolitan Office of Education [SMOE] (2004) has tried to center students' experiment and inquiry on its science education by forming the Task Force for Revitalization of

Science Education that has supported a variety of school science fairs, teachers' professional development, and schools' attempts to improve laboratory facilities.

Personally, I have been seeking for answers to a question: in this Information and Communication Age, how can I compete with and win over non-classroom instructors? In Korea, there are so many free/charged websites that have archives of videos and scripts for science instruction, including Korean Educational Broadcasting System. Furthermore, students go to private institutes after school to take classes in order to cram for their school's final exams and eventually the Korean SAT. Instructors from these websites and cram schools impart the factual knowledge that has the most probability to be on the tests, and the skills to select correct answers from multiple choice questions. As a result, classroom teachers face a serious threat.

To confront the threat, I set a goal of my practice as teaching for deep conceptual understanding. Perkins (1993) advised that teaching for understanding should be focused on what the teacher gets the students to do rather than what the teacher does. Furthermore, studies based on constructivism showed the importance of active learning and reflective teaching (Driver, Asoko, Leach, Mortimer & Scott, 1994). Cognitive research, particularly the theory of conceptual change, suggested that science instruction be improved by building students' conceptual understanding (Bruer, 1994; Duit & Treagust, 2003; Gardner, 1993).

In addition, I tried to find an effective way to incorporate students' experiments in my teaching practice to achieve the goal because in science education what students do in their learning is closely related to their laboratory activities. Student experiment also seems to have a potential to help me compete with non-classroom instructors who just give lectures. Indeed, the school science laboratory has been given a central and distinctive role in science education, helping students understand abstract concepts and develop reasoning skills and scientific method of investigation to a degree that cannot be accomplished by the teacher's lecture or demonstration alone (Allen, Baker & Ramsden, 1986; Domin, 2007; Hofstein & Lunetta, 2004). Nevertheless, traditional school experiments have been blamed as “cookbook exercises” because students are not stimulated intellectually and thus not motivated by using highly structured materials to verify concepts presented previously in lecture (Allen et al., 1986; Monteyne & Cracolice, 2004). Admittedly, students in traditional labs follow written instructions and fill in the blanks of data tables so that they can ascertain that what the teacher or the textbook told them was true. Besides, there are so many video clips and simulation programs that show the process and results of school experiments that students and teachers don't need to conduct an experiment to find out the results. Thus, the focus of carrying out experiments in high schools has been shifted from acquiring the skill of handling tools and equipment to understanding its underlying concepts and scientific reasoning skills. In Korean high school introductory chemistry books (Chemistry I), there are many activities in which only analysis of given data is required so that time can be saved to cover many content topics. However, opportunity to learn science through a process of inquiry seemed to have significant advantages. During the investigation, students learn not only content knowledge but also develop scientific reasoning ability (NRC, 2000). Particularly, guided inquiry laboratory, also known as structured discovery laboratory, which is defined as an experiment where the students discover the concept for themselves by analyzing their own laboratory data, appeared a practical way to teach the content and the inquiry method of chemistry in a high school environment (Allen et al., 1986; Colburn, 2000; Domin, 2007; Mayer, 2004).

Thus, the work presented in this paper was the investigation and reflection about the effects of guided inquiry-based chemistry laboratory instruction on the conceptual development of Korean 11th grade students' understanding about metal.

Research questions

The purpose of this research was to examine the question: how do inquiry-based laboratory activities affect students' conceptual understanding? The followings are two specific aspects I investigated to answer my research question:

1. How did the students' concepts of metal evolve through guided inquiry-based laboratory activities?
2. What were the strengths and limitations of the inquiry-based laboratory for the students' conceptual understanding?

Importance of study

This action research project helped me develop my pedagogical content knowledge, allowing me to pursue my life-long wondering: How much can students learn only from their laboratory activity without my prior instruction? The findings from this study deepened my commitment to teaching for understanding and sharpened the focus of my teaching efforts on the inquiry method.

In addition, this paper has a value as a research paper with useful information for chemistry teachers. One feature of this research is that this study tried to connect the theory of the concept change with the method of inquiry. There have been three kinds of research: research on conceptual change theory, research on the inquiry method, and research on school laboratory. However, I couldn't find any paper that incorporated all of them in a research. This paper suggests how these three areas can be integrated in a research.

The second feature is that this paper focused on the learning path, not only the final result. So far, while research findings have been helpful in identifying problematic conceptions, less is known regarding the pace at which students are capable of undergoing conceptual change with effective instructional experiences (NRC, 2005). This paper shows the evolution of a concept with learning activities.

The third feature is that the content topic of this paper is novel. There have been so many papers that studied about the conceptual development in physics and biology, but not many about chemistry. Especially, the concept of metal is a totally new topic in science education research.

Finally, this paper examined the effects of laboratory instruction on student learning. While the laboratory provides a unique medium for teaching and learning in science, there is insufficient data to confirm or reject convincingly many of the statements that have been made about the importance and the effects of laboratory teaching (Hofstein & Lunetta, 2004). This research tried to show relationships between experiences in the laboratory and student learning.

I just hope this research conducted by classroom teacher to bridge the 'theory-practice' gap (Duit & Treagust, 2003, p. 683).

Literature review

Understanding scientific knowledge often requires a change in what people notice and understand about everyday phenomena (NRC, 2005). Also, a learner needs to directly experience, construct, act upon, test, or revise knowledge to understand. However, it is the teacher that is responsible for providing a learning environment for the learner (Driver et al, 1994; Holzer, 1994; Perkins, 1993; Vosniadou, Dimitrakopoulou, & Papademetriou, 2001). Thus, in order to create a learning environment that allows students to undergo important changes in their views and understanding, I examined two areas: theory of conceptual change as a learning process and inquiry as a way of teaching chemistry.

Theory of Conceptual Change

So far, many conceptual change studies have been conducted to investigate the development of students from preconceptions towards the intended scientific concepts (Duit & Treagust, 2003). However, when it comes to prior knowledge as an important factor in the success of instructions, two major approaches in the conceptual change theories seem to be taken. The roles prior knowledge plays in science learning could be either necessary or problematic (Fisher, 2004; Taber, 2001). One school of researchers insists that students' wrong ideas should be replaced. The other school of researchers argues that students' naïve ideas should be differentiated and integrated into a new structure of knowledge.

Prior knowledge as a foundation of learning

In several studies, Constructivists claimed that learning of science is the knowledge construction on what already exist in their cognitive structures as they actively try to make sense of their experiences (Driver, Squires, Ruthworth & Wood-Robinson, 1993; Duit & Treagust, 2003; Gilbert, Osborne & Fensham, 1982; Singer, Marx, Krajcik, & Chambers, 2000). Students come to the science classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may memorize them for tests (NRC, 2005).

In the book *Making Sense of Secondary Science*, Driver et al. (1993) pointed out the importance of students' prior knowledge. Their investigations indicated that before instructions, students already hold deeply rooted conceptions and beliefs. Furthermore, students have unique ways of construing events and phenomena which are coherent and fit with their experience, yet which might differ substantially from the scientific view to be taught. Therefore, they stressed that effective science teaching should take account of students' pre-instructional ideas and provide activities which enable students to make the transition from their current understandings to a more scientific view. They suggested five ways to respond to students' preconceptions.

- Developing existing ideas.
- Differentiating existing ideas.
- Integrating existing ideas.
- Changing existing ideas.
- Introducing new ideas (p. 10).

Similarly, Bruer (1994) pointed out that it is challenging for teachers to understand students' theories and concepts and to build effective instruction on them, which helps students map their informal understanding of how the world works onto the formal scientific theories they encounter in school. Therefore, the first thing to do in planning instruction is to consider the nature of any differences between students' prevalent ideas and the science viewpoint.

From the same point of view, Taber (2001) developed a useful typology that could help teachers circumvent students' learning impediments, diagnose the causes for 'failures' in learning, and plan effective remedial action. In his typology, there are four types of learning impediments caused by the nature of prior knowledge:

- Deficiency: no relevant material held in existing cognitive structure.
- Fragmentation: learner does not see relevance of material held in cognitive structure to presented material.
- Ontological: presented material inconsistent with intuitive ideas about the world

held in cognitive structure.

- Pedagogic: Presented material inconsistent with ideas in cognitive structure deriving from prior teaching.

However, the primary distinction is between situations when the intended learning fails to take place because: (a) the learner cannot understand the presented material in terms of existing ideas (Null impediment); or (b) the learner interprets the new material in terms of existing, but alternative, ideas (substantive impediment).

In sum, prior knowledge is a kind of preconceptions that shape subsequent learning. New understandings are contingent on existing understandings and experiences. Therefore, students' prior knowledge should be seen as a cognitive structure that they have developed from their daily life experiences and formal education rather than simply pieces of misconceptions. From a teaching perspective, what seems to be the starting point to promote any change in the conceptual structure is to lead the individual to be aware of the differences between their prior knowledge and the new information (Limon, 2001).

Conceptual change theory as a replacement of problematic preconception

One aspect of prior knowledge is a barrier to learning that interferes with, rather than contribute to, students' development of expertise. Thus, they should be confronted and replaced by valid ones in order for scientific knowledge to be understood (Fisher, 2004; McCloskey &

Kargon, 1988; Roschelle, 1995; Taber, 2001). McCloskey and Kargon (1988) found that misconceptions in physics came from an intuitive theory of motion which was similar to the pre-Newtonian theory of mechanics, or the medieval theory of impetus. For example, an object in motion is believed to stop without a force acting upon it by students and medieval scientists, whereas it is viewed to keep moving at a constant speed by modern physicists. These intuitive ideas are also called alternative conceptions because, as Fensham (1972) pointed out, the learner's prior knowledge could be a wrong anchor that causes misunderstanding of new knowledge. Hammer (1996) suggested that a teaching intervention should draw out or activate misconception which students had not sufficiently articulated. This step is crucial for problem recognition in the learning process. However, if confronting a misconception is so soon that the misconception has not been sufficiently articulated, the intervention will be ineffective. On the other hand, there is a risk in waiting that the discussion will reinforce the misconception.

Consequently, the theory of conceptual change came to light in 1980s with an aim of the replacement of misconceptions by scientifically accepted ones. Posner, Strike, Hewson and Gertzog (1982) merged Piagetian notions of assimilation and accommodation, and Kuhnian ideas of paradigm shift in the history of science into the conceptual change model. Their theory of conceptual change was based on the philosophy of science that suggests the following conditions for a successful conceptual change to take place.

- There must be *dissatisfaction* with current conceptions: Learners need to realize that their old conception has become dysfunctional in order to change it.
- A new conception must be *intelligible*: Learners need to find a new conception comprehensible in order to explore it and thereby make a new conception a candidate to replace some dysfunctional conception.
- A new conception must appear initially *plausible*: It should have potential to solve or dissolve outstanding problems with current conceptions and consistency with other well-established beliefs.
- A new conception should be *fruitful*: It should be thought of a productive tool of problem solving (Strike & Posner, 1992).

These conditions assume that learning takes place in a conceptual context called conceptual ecology that consists of such cognitive artifacts as anomalies, analogies, metaphors, epistemological beliefs, meta physical beliefs, knowledge from other areas of inquiry, and knowledge of competing conceptions. Two pedagogical implications of its aspects include an inventory of the kinds of cognitive artifacts that learners are likely to possess and that must be taken into account by teachers. Second, they suggest the kinds of things that teachers may provide in instruction in order to facilitate conceptual change (Strike & Posner, 1992).

In the conceptual change model, student dissatisfaction with a prior conception was believed to initiate dramatic or revolutionary conceptual change. Resolution of conceptual competition is explained in terms of the comparative intelligibility, plausibility and fruitfulness of rival conceptions (Harrison & Treagust, 2001). If the learner was dissatisfied with his/her prior conception and an available replacement conception was intelligible, plausible and fruitful, accommodation of the new conception may follow.

Hewson refined the conceptual change model by analyzing the conceptual status (see Hewson, 1982; Hewson & Lemberger, 2000; Hewson & Thorley, 1989). The conceptual status is particularly useful for assessing changes in students' conceptions while learning. When a competing conception does not generate any cognitive conflict, the new conception may be assimilated alongside the old, which is called 'conceptual capture'. When dissatisfaction between competing conceptions reveals their incompatibility, two things may happen. If the new conception achieves higher status than the prior conception, accommodation, which is called conceptual exchange, may occur. If the old conception retains higher status, conceptual exchange will not proceed for the time being (Hewson & Hewson, 1984 as cited Duit & Treagust, 2003). It should be noticed that a replaced conception doesn't disappear and the learner may reinstate it later, and that it is the student, not the teacher, who makes the decisions about conceptual status and conceptual changes.

The strategy of cognitive conflict for conceptual change

Early theories of conceptual change considered the phase of conflict, generated by dissatisfaction with the existing concepts, as a first step to reach conceptual change. It was assumed that if discrepant data dissatisfy students, they will realize that their preconceptions are inadequate to explain the new experience, leading them to consider new conceptions that can account for the discrepant data. Thus, there are many studies that were centered on the concept of cognitive conflict induced by discrepant events as an initiation of conceptual change (Limon, 2001). Generally, a discrepant event is the physical experience that provides students with novel evidence to contradict their existing conceptions. The instructional use of a discrepant event was supposed to induce cognitive conflict. (Kang, Scharmann & Noh, 2004). However, the findings of those studies seem to be equivocal (Limon, 2001).

For example, Chinn and Brewer (1998) conducted a research to investigate the types of responses to discrepancy under the assumption that in many fundamental ways science students are like scientists. There were four crucial elements in this assumption. First, like scientists, science students possess beliefs about how the physical world operates. Second, both scientists and science students can detect anomalies. That is, both scientists and science students notice when new data are incompatible with their prior beliefs. Third, science students are like scientists in that they recognize that these anomalies pose a threat to their current theories. Finally, like scientists, science students will sometimes choose to adopt an alternative theory in response to data that are anomalous for their prior theory. However, they found several ways in which students respond to anomalous data: (a) ignoring the data; (b) rejecting the data; (c) professing uncertainty about the validity of the data; (d) excluding the data; (e) holding the data in abeyance; (f) reinterpreting the data; (g) accepting the data and making peripheral theory change; and (h), accepting the data and changing their theory. Less than 10 % of participants underwent conceptual change to some degree. On the other hand, Kang, Scharmann and Noh (2004) found only 7 types of responses to a discrepant event in which they have belief decrease instead of ignoring and abeyance. They explained that belief decrease is feeling dissatisfaction with their existing conceptions but not being confident of their decisions. In their research, over 60% students changed their preconceptions to some extent.

Nevertheless, findings of these two studies have made it clear that it is not enough for science instruction simply to inform students of scientific conceptions because students in many cases do not necessarily arouse cognitive conflict through merely experiencing a discrepant event.

This is consistent with the fact that preconceptions can lead students to simply not notice, quickly dismiss, or not believe what they do not expect to see (NRC, 2005; Roschelle, 1995). It was concluded that cognitive conflict may be just one of the important factors to be considered, not a necessary condition, for conceptual change in learning science concepts (Chinn & Brewer, 1998; Kang, Scharmann & Noh, 2004; Limon, 2001).

The importance of learning attitude in conceptual change

Chan, Burtis and Bereiter (1997) examined how students process scientific information that contradicts what they believe, and assessed the contribution of this knowledge processing activity to conceptual change. Two major processes were identified in their research: direct assimilation, which involved fitting new information with what was already known, and knowledge building, which involved treating new information as something problematic that needed to be explained. They elaborated a knowledge-processing activity scale to evaluate individuals' reactions to the processing of contradictory information. It consisted of the following five levels:

1. *Subassimilation*: new information is reacted to at an associative level;
2. *direct assimilation*: new information is either assimilated as if it was something already known or excluded if it does not fit with prior beliefs;
3. *surface-constructive*: new information is comprehended, but its implications for one's beliefs are not considered;

4. *implicit knowledge building*: new information is treated as something problematic that needs to be explained;
5. *explicit knowledge building*: new information is accumulated for constructing coherence in domain understanding (p. 12).

They found that the level of knowledge processing activity exerted a direct effect on conceptual change and that this activity mediated the effect of cognitive conflict. Knowledge building as a mediator of conflict in conceptual change explains the previous equivocal research findings about the effect of anomalous data. It also highlights the importance of students' active learning attitude in the process of conceptual change.

Conceptual change theory as a restructuring of preconception

Even though the classical model of conceptual change (e.g. Posner et al., 1982) explained the conceptual change focusing on incompatibility between two distinct and equally well-organized explanatory systems, one of which need to be abandoned in favor of the other, the findings of recent studies suggested that conceptual change is evolutionary, not revolutionary. Conceptual change is a slow revision of an initial conceptual system through the gradual incorporation of elements of the scientific explanations, and there seems to be many learning paths from students' prior knowledge to the science concepts (diSeass, 2001). It is especially important for its instructional implications to know more about the intermediate steps that follow the initial step of meaningful cognitive conflict, and not to assume that this process is necessarily linear (Limon, 2001).

As a result, the term conceptual change is now used to describe the complex process of learning in such domains where the pre-instructional conceptual structures of the learners have to be fundamentally restructured in order to allow understanding of the intended knowledge (Appleton, 1997; Duit & Treagust, 2003; Vosniadou et al., 2001). Thus, in this paper, conceptual change, conceptual understanding, knowledge acquisition, and conceptual development are utilized to express the same meaning as the science learning process.

Hammer (1996) proposed that students' prior knowledge may include reasonable conceptions that are not congruent with expert understanding, so teachers must help students modify or refine their alternative conceptions. From the same perspective, diSessa (1983, 1993, 2001) proposed a theoretical framework that explains the evolution of conceptual change in learners' minds. According to him, learners' cognitive structures are composed of primitive notions which involves many simple elements called "phenomenological primitives" (p-prims for short) (diSessa, 1983, p. 16) as minimal abstractions of simple common phenomena. P-prims are small and numerous intuitive elements of knowledge systems that are often quite context specific in their activation (diSessa, 2001, p. 29). They come from direct life experiences, so their origins are relatively unproblematic. They are involved in and contribute to both naïve and expert understanding, and they do not interfere with student's development of expertise. Rather, they are essential to it.

diSessa has been concerned about the development and contribution of p-prims in physics understanding from naïve to novice to expert. From his perspective, physics-naïve students have a large unstructured collection of p-prims, with which they see and sometimes explain the world. P-prims are not the laws of physics, but intuitive equivalent of them. P-prims act largely by recognition. The recognition of p-prims can serve as heuristic cues to specific, more technical analyses. In a process of abstraction, some p-prims are compatible with the formal physics. Thus, they become involved in expert thought, acquiring a higher priority than the others in their cognitive structures, whereas some p-prims lose their status and are cut apart from the cognitive structures because they can be explained by more fundamental, higher priority ideas. He stressed that the recognition of p-prims is a fundamental operation of the human cognitive structure. When a learner tries to analyze a phenomenon, s/he selects some of her/his p-prims to explain it. The difference between naïve and expert is the choice of p-prims. Experts select the higher priority of p-prims than novices.

In the course of learning, students increase the number of p-prims available in a context. However, a more drastic revision in the intuitive knowledge system is in the change in function of p-prims from relatively isolated, self-explanatory entities to pieces of a larger priority network. In fact, p-prims become reorganized and prioritized into a structured knowledge system called "coordination class" (diSessa, 2001, p. 43). Also, contexts of activation may migrate, expand, or contract, depending on p-prims' new roles in the developing knowledge system. Coordination classes provide the means for getting a certain class of information from the world. Thus, the depth, breadth, and integration of the expert's coordination classes mark a major conceptual change from intuitive physics.

Consequently, he suggested that in order to recognize and deal with the diversity and complexity involved in conceptual change, two things in the learner's knowledge system need to be considered: p-prims and coordination classes. To increase the multiplicity, p-prims should be differentiated and increased. To increase the systematicity, coordination classes should be organized and contextualized. Scientific concepts are complex and finely configured systems involving named parts and relation.

Guided Inquiry Laboratory

In this section of review, I asked a fundamental question: why do we use lab activities in our instruction? Since the laboratory activities are conceptually integrated in the high school science, it is important to rethink the role and practice of laboratory work in science teaching.

Hofstein and Lunetta (2004) wrote that there was a need for research that would assess how time spent in laboratory activities and how the nature of students' activities in the laboratory affect their learning. Therefore, I examined the goals of science teaching and learning to identify optimal activities from all modes of instruction that will best facilitate the goals. There is a real need to pursue vigorously research on learning through laboratory activities to capitalize on the uniqueness of this mode of instruction for certain learning outcomes (Hofstein & Lunetta, 2004).

Traditional laboratory activity in high school science

The laboratory has been playing a central, distinctive role in science education. Hofstein and Lunetta (2004) defined science laboratory activities as learning experiences in which students interact with materials and/or with models to observe and understand the natural world. *The National Science Education Standards in the United States* (NRC, 1996) suggested that school science laboratories have the potential to be an important unique medium for introducing students to central conceptual and procedural knowledge and skills in science.

Indeed, using laboratory has many advantages. It helps students build up their understanding of scientific concepts, science inquiry skills, and perceptions of science by doing sciences. The science laboratory also provides a setting in which students are centered and work cooperatively in small groups to investigate scientific phenomena (Hofstein & Lunetta, 2004).

Tobin (1990) wrote that "Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science" (p. 405).

However, the effectiveness of the laboratory as a unique learning environment depends markedly on the nature of the activities conducted in the lab, the expectations of the teacher (and the students), and the nature of assessment. Hofstein and Lunetta (2004) pointed out that many students engage in laboratory activities in which they follow recipes and fill in a series of blanks on a worksheet without a clear sense of the purposes and procedures of their investigation and their interconnections. Students are seldom given opportunities to use higher-level cognitive skills or to discuss substantive scientific knowledge associated with the investigation, and many of the tasks presented to them continue to follow a "cookbook" approach. Thinking processes such as decision making skills are excluded in the traditional school lab. Just because physically involved doesn't mean cognitively active. The focus of school lab should be on learning by thinking, not learning by doing.

Therefore, it is critical to consider the factors that continue to inhibit learning in the school science laboratory such as :

- Many of the activities outlined for students in laboratory guides continue to offer "cook-book" lists of tasks for students to follow ritualistically. They do not engage students in thinking about the larger purposes of their investigation and of the sequence of tasks they need to pursue to achieve those ends.

- Assessment of students' practical knowledge and abilities and of the purposes of laboratory inquiry tends to be seriously neglected, even by high stakes tests that purport to assess science standards. Thus many students do not perceive laboratory experiences to be particularly important in their learning.

- Teachers and school administrators are often not well informed about what is suggested as best professional practice, and they do not understand the rationale behind such suggestions. Thus, there is a high potential for mismatch between a teacher's rhetoric and practice that is likely to influence students' perceptions and behaviors in laboratory work.

- Incorporating inquiry-type activities in school science is inhibited by limitations in resources (including access to appropriate technology tools) and by lack of sufficient time for teachers to become informed and to develop and implement appropriate science curricula. Other inhibiting factors include large classes, inflexible scheduling of laboratory facilities, and the perceived foci of external examinations. (Hofstein & Lunetta, 2004, p. 47)

Essences of Inquiry

A prominent feature of The National Science Education Standards (NRC, 1996) is a focus on inquiry. In order to guide educators understand and commit to inquiry in the Standards, the book Inquiry and the National Science Education Standard (NRC, 2000) was released. In the book, the term "inquiry" is used to describe two aspects in the Standards. According to the *Standards* and *Inquiry*, the word "inquiry" encompasses the understanding of inquiry and of how inquiry results in scientific knowledge as well as the ability to inquiry. In this way, the Standards strive to build student understanding of how we know what we know and what evidence supports what we know.

In the content standards, two aspects of inquiry are specified. First, the standards on the fundamental abilities necessary to do scientific inquiry require high school students to do the followings:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigation and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument (NRC, 2000, p. 19).

Second, the standards on the fundamental understanding about scientific inquiry demand high school students to understand the followings:

- Scientists usually inquire about how physical, living, or designed systems function.
- Scientists conduct investigations for a wide variety of reasons.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Mathematics is essential in scientific inquiry.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Results of scientific inquiry – new knowledge and methods – emerge from different types of investigations and public communication among scientists (NRC, 2000, p. 20).

Teaching through inquiry has implications for essential features of classroom inquiry.

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations (NRC, 2000, p. 25).

Taken as a whole, while helping students develop clearer and deeper understanding of some particular concepts, these essential features introduce students to many important aspects of science.

The amount of detailed guidance a teach provide in an activity or the extent to which students initiate and design an investigation vary from "open" to "guided." The more responsibility students have for conducting an activity, the more "open" the inquiry; the more responsibility teacher takes, the more "guided" the inquiry. In making decision about the amount of guidance, a key element is the intended outcomes of the activity. One teaching strategy could be a series of laboratory activities framed by questions asking the gathering and use of evidence to develop explanations about a scientific conception.

In sum, inquiry asks us to think about what we know, why we know, and how we have come to know and suggests how to teach science in a classroom.

Guided inquiry as integration of the method of lab and the idea of inquiry

There may be many types of laboratory instruction, but Domin (1999, 2007) offered the useful taxonomy of laboratory instruction styles to highlight the distinct features of each style. In his classification of laboratory instruction, he focused on three descriptors: outcome, approach, and procedure; there were four distinct styles of laboratory instruction: expository, inquiry, discovery, and problem-based. According to Domin's taxonomy, the guided-inquiry laboratory is fell into the category of discovery. Discovery labs take a heuristic approach in which the outcome of experiment is predetermined by the teacher, but students don't know the expected outcome; its inductive nature help students develop a general understanding of the underlying concepts by studying specific examples of a phenomenon.

However, there seems to be some dispute about the procedure in the guided inquiry. Domin (1999, 2007) argued that the procedure of experiments was given by the teacher or a manual, but Colburn (2000) insisted in his classification of inquiry that the procedure should be devised by the students in discovery lab. This conflict can be resolved by Mayer (2004) who argued that pure discovery is more sterile than structured discovery learning in his article "*Should There Be a Three-Strikes Rule Against Pure Discovery Learning?*" By and large, guided inquiry seems to be consistent with structured discovery laboratory. However, I found there could be a variation about the procedure depending on the ability of students. College students generated procedures, but secondary students were given by the instructor (Allen et al., 1986; Domin, 1999; Colburn, 2000; NRC, 2005). Monteyne and Cracolice (2004) concluded, "A key element of guided inquiry is that data analysis is left to the student, but not the data collection (p.1159)." The process of analysis is precisely what defines a guided inquiry learning environment in which students have the opportunity to develop their thinking skills and conceptual understandings. It is also critical to have a knowledgeable laboratory instructor who can mediate students' thinking skills development and knowledge acquisition for a guided inquiry to be successful (Monteyne & Cracolice, 2004).

Advantages of guided inquiry laboratory

The nature of laboratory instruction is important because it determines the learning environment that may lead to different learning outcomes (Domin, 2007; Vosniadou et al., 2001). According to Gunstone (1991), the challenge of the school laboratory is to help learners take control of their own learning in the search for understanding. In the process, it is vital to provide opportunities that encourage learners to do inquiry, that is, "minds-on as well as hands-on" in the laboratory.

Open inquiry is desirable to develop the abilities to inquiry. However, when understanding requires careful attention and logical development, especially when the teacher is responsible for the learning of 30 or more students, guided inquiry is best (NRC, 2005). Besides, the ability and cognitive developmental level of students should be taken into consideration when specific type of laboratory instruction is chosen (Charlton, 1980; Colburn, 2000; Vosniadou et al., 2001). Guided-inquiry laboratory was reported to be advantageous for embracing students of diverse abilities and cognitive developmental stages (Ault, 2002; Charlton, 1980). In fact, both students and teachers alike need time to gradually make a transition from the traditional type activities and lectures to inquiry-based instruction. The more familiar the activity, materials, and context of the investigation, the easier it is for students to learn through inquiry (Colburn, 2000).

Particularly, when students are not familiar with chemical experiments in inquiry-based laboratory, the chemistry lab should be structured with clear and safe instructions that increase their chance of success (Monteyne & Cracolice, 2004). In brief, since the students in this study lack experience with inquiry and deal with chemicals, the guided inquiry-based laboratory is suitable choice for my instructional mode.

Asking questions in guided-inquiry based laboratory

In a guided inquiry activity, although students make observations and draw conclusions, it is a teacher who guides students with relevant questions that foster student thinking (NRC, 2005). Learning objectives are usually presented as open-ended, or divergent, questions. Activities are centered on questions that students can answer directly via investigation. To keep students thinking, teachers should not give answers but present opportunities for students to test their answers (Colburn, 2000). In addition, Ault (2002) argued that the procedure was a point of departure of investigation, and that, if used thoughtfully, it could develop skills and provide insight. The word "thoughtfully" implies the teacher should ask such questions as "Why do we need to do that?" or "What are some different things you could try with that procedure?" to provoke students' thought. In this study, an array of open-ended questions that required higher levels of reasoning were used in students' handouts in order to guide students' activities and to collect data for the research.

Laboratory for conceptual change

For instruction to be successful, it is important to match an appropriate type of laboratory to its intended outcomes (Domin, 2007). In this study, the purpose of using guided inquiry laboratory is to promote understanding of content knowledge, not inquiry itself. When laboratory experiences are integrated with other metacognitive learning experiences and when they incorporate the manipulation of ideas instead of simply materials and procedures, they can promote the conceptual learning of science. If guided inquiry laboratory activities are integrated into an effective teaching strategy, they support students in their conceptual changes because investigation involves the interaction of content and process (NRC, 2005). Observing is not enough to produce conceptual change, and background knowledge is required to make sense of new observations. It may appear to be more about process because what students observe is a function of when, how, and with what tools we choose to observe. However, what students observe is also a function of what they expect to observe, and how they interpret their observation are clearly influenced by what they already know and believe about the physical world (NRC, 2005).

Some types of teaching strategies proved to be effective in inducing conceptual change by identifying prior knowledge and providing discrepancy and anomaly. I found Minstrell's teaching strategy a typical example of guided inquiry. Minstrell (as cited in Bruer, 1994) conducted several 'crucial experiments' to teach the concept of gravity to high school students. Each crucial experiment was a kind of discrepant events that placed students in conflict after a 'benchmark' discussion. In the benchmark lesson, he and his students dissected their qualitative reasoning about vivid, everyday physics problems into facets. They became aware of the limitations of each facet, and they identified which facets were useful for understanding a particular phenomenon. They then explored how appropriate facets could be combined into powerful explanations that could be used to solve other problems.

Furthermore, the instructional model of learning cycle proposed by Atkin and Karpulus based on the Piaget's work could promote conceptual understanding (NRC, 2000). Although the learning cycle has undergone elaboration and modification over time, its phases and sequence are typically presented as exploration, invention, and discovery. In this model, exploration could be the guided inquiry laboratory activities in which students gather information they need to learn a concept. Invention refers to the formal statement of a new concept, in which students interpret newly acquired information by restructuring their prior concepts. Discovery involves applying the new concept to a novel situation. My research method, the guided-inquiry based laboratory, could be compared to the step of exploration in the learning cycle.

Method

Participants

The participants of this action research project were 158 students (108 male and 50 female) of 11th grade from five classes of a high school in Seoul, Korea. They were very homogenous in terms of ethnicity because Korea has only one race, Korean, and they are from the same local middle class community. In terms of achievement, female students usually performed better than male students, but their achievement gab among classes was not significantly wide (see Table 1 as a reference). What's more, because all of them were college bound and pursuing science and engineering majors, they considered science subjects to be important. They were taught Chemistry I (the subject name) three periods (50 minutes per period) a week.

Table 1. Participants' achievement on the second semester midterm test in 2007

Class No.	1	2	8	10	11
Average score	89.35	85.9	77.62	74.69	79.52
Mean	81.42				
SD	6.05				

Context of Study

My action research was designed to improve my pedagogical content knowledge, but I was not able to teach in a classroom for such a long term because I am a chemistry teacher of

Korea, but have been studying in the California State University, Northridge with a fellowship from Korean Government. Therefore, I asked a friend of mine who has taught Chemistry in a high school in Seoul, Korea to help me with this research project. She has the same educational background and teaching experience as mine. I provided her with guided-inquiry based laboratory activities I designed with detailed directions. Honestly, this was one of reasons why I chose the guided-inquiry based laboratory as a method employed in my project. If the other teacher instead of me had given lectures to the students with my direction, it could not have been my action that affected the result of the study because lecturing involves too many variables to be controlled.

For this study, I just focused on the laboratory activities, not classroom lectures. From the unit Metal, four student experiments were designed and carried out sequentially in successive weeks. After each lab activity, the students were given a lecture to complement their learning from the activity with more explanations and to cover other relevant topics. Thus, whole instructional strategy could be similar to a learning cycle (Colburn, 2000). However, during the laboratory experiments the students were introduced to not only target concepts but also terms and application of the concepts because it was the lab activities where the students were supposed to develop understanding of the target concepts.

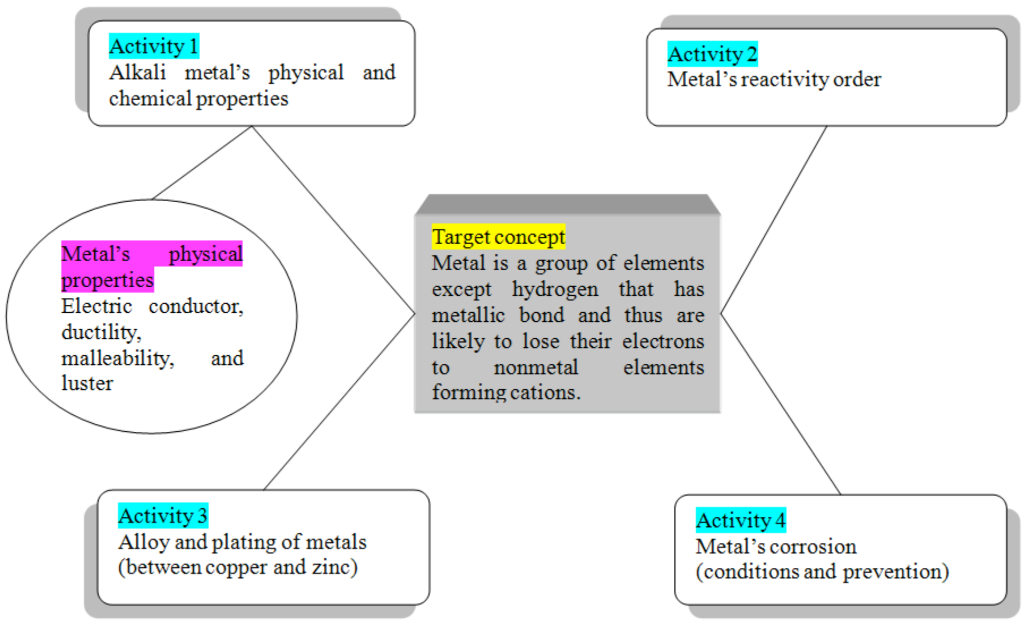
To guide the students in the inquiry activities, I gave them some brief background information about the purpose of the activities and well structured procedures in handouts I had made, and they were asked to answer a series of questions (see Appendix B). Students made hypotheses about *a driving question* and *subquestions*, conducted experimentations, analyzed data, and then drew conclusions by discussing with other students in their groups.

During the investigation the teacher's role was to monitor students' use of materials and interactions with others, as well as to attend to the conceptual ideas on which students were working. Only when the teacher judged that the students' activity was so off the track that the targeted learning goals could be sacrificed, she provided prompt corrective feedbacks.

Subject, Unit and Topics of Student Experiments

The curricular purpose of Chemistry I is to promote scientific literacy with a context-based approach as an introductory chemistry course for Korean high school. Chemistry I is taught for 11th grade students and composed of five units: Air, Water, Metal, Carbon Compounds, and Carbon Compounds' derivatives. This study focused on the unit *Metal*. The unit *Metal* includes concepts about metals' physical properties, reactivity order, oxidation-reduction reactions of metal and prevention of corrosion. Because these concepts are taught again in Chemistry II with more focus on the chemical bonds, the unit Metal emphasizes the applications in our life such as metal's uses, refining techniques, corrosion, protecting methods, recycling, and alloys.

Figure 1. Schematic framework of concepts for the activities in this study



To develop competence in an area of inquiry, students must understand facts and ideas in a conceptual framework (NRC, 2005). So I developed a conceptual framework for the instructions based on the national curricular objectives (see Figure 1). When I designed the activities, I kept in my mind 'continuity of curriculum' for the progression of students' ideas (see Figure 1). The term "progression" was applied to changes that happened inside a learner's head, and the word "continuity" was connections of the activities organized by the teacher around the target concept around which the other concepts are arranged in the framework (Driver et al., 1993, p.12).

The target concept was investigated with a *driving question* to monitor the process of conceptual change. The driving question was "How would you define metal from a chemist's perspective?" However, I included the driving question only in Activity 1 and 2 because I made a mistake of dropping the question in Activity 3 and 4 when I designed the activities. When I made the worksheets, I thought that Activity 3 and 4 were not directly related to the concept of metal, but I should have included the question to monitor the whole process of conceptual change throughout the unit.

However, the following *subquestions* are used in all four activities to measure the learning of the objectives of each laboratory.

- Activity 1: Why can we not see lithium, sodium, and potassium metals in the nature? (The characteristics of alkaline metal)
- Activity 2: How can we determine the reactivity order of metals? (The reactivity series of metals)
- Activity 3: What's the difference between alloy and plated metals? (Plating and alloy)
- Activity 4: What causes metals' corrosion? (The conditions of corrosion)

Collection and Analysis of Data

My research project relied mainly on the analysis of student documents to answer the research questions. My ultimate purpose of the project was to investigate the effect of inquiry laboratory on the students' conceptual development. Thus, for the first question, how did the students' concept of metal evolve with the laboratory activities, I collected and compared four tests: the pre and post tests (see Appendix A) and two formative tests from Activity 1 and 2 (see Appendix B). One thing that I should mention for the collection of the data is that the posttest was accidentally taken three months later than it should. So the post test is a delayed post test. I carefully read the students' responses to the driving question in the four tests many times and finally came up with the code scheme (see Table 2).

Table 2. Code scheme for the analysis of concept of metal

Category	Codes	Concept
Physical Properties of metal	A	matter that conduct (heat) and electricity
	B	matter that has malleability and ductility
	C	matter that has metallic luster
	D	matter in a solid state at room temperature
	E	matter that has free electrons
	F	matter that is dense and hard
	G	matter that has crystal structure of atoms
	H	matter that has magnetism
	I	matter that is like iron
Chemical Properties of metal	1	elements that readily lose electrons to form positive ions (cations)
	2	elements that has metallic bond between cations and free electrons
	3	elements that are likely to be oxidized (rusted)
	4	elements that react with acids generating hydrogen gas

	5	elements that react with water generating hydrogen gas
	6	elements that are placed at the lower left on the periodic table.
	7	elements composed of cations that are solidified
	8	elements that are strongly reactive
	9	elements that have strong reducing ability
	10	elements become basic when dissolved in water

Then I coded each student's response in every test (see Appendix D to see the summary of coded responses) and put the data into the MS excel program. Each response of a student in a test was in a cell. Thus there were four columns of 158 cells in the raw data because there were four tests of 158 students. Then I looked for the distributions of the concepts with graphs. As a result, I decided to monitor the changes in the numbers of students who had the big seven concepts with the "Filtering" function of the MS Excel program. For the more in-depth analysis, I tracked down the changes of the concepts with only two Concept 1 and A.

In addition, in order to find answers for the second question, what are the strengths and limitations of the inquiry laboratory for the conceptual understanding?, I used four formative tests from the **lab worksheets** of the four students' experiments, the **result of their midterm test as a summative test** (see Appendix C to see the questions and the results) and a **survey of students' attitudes toward guided inquiry laboratory**. For the summative test, I created six questions from the driving questions and the subquestions and put them on their midterm test with other 14 questions that were developed by the teacher so as to measure the achievement of their learning objectives of the unit. With the test results I measured the achievement of learning objectives to find the effectiveness of the inquiry activities for learning content knowledge. Besides, I solicited the students' opinions in the survey about the efficiency of the activities.

Timeline for the Collection of the Data

- The pretest: from 11 to 15 in June 2007
- Activity 1 and the first formative test: from 27 to 29 in August 2007
- Activity 2 and the second formative test: from 3 to 5 in September 2007
- Activity 3 and the third formative test: from 10 to 12 in September 2007
- Activity 4 and the forth formative test: from 17 to 19 in September 2007
- The summative test on October 1, 2007
- The survey: from 8 to 10 in October 2007
- The delayed post test: from 17 to 19 in December 2007

Findings

Evolution of Students' Concepts of Metal

In this section, I collected evidences for the conceptual change of students about metal. I used four tests' results to monitor the change.

General view of students' concepts of metal

First of all, I analyzed the students' responses to the driving question in four tests and found out a plenty of ideas at a variety of levels. Each code in Table 2 represents a distinctive concept about metals' properties. Majority of the students had more than one concept in their responses. Therefore, I coded all the concepts with the code scheme in the students' responses (see Appendix D). Then I made Table 3 to show the whole view of the students' concepts. Students' ideas about metal in Table 2 and 3 consisted of two major categories: physical properties and chemical properties. Therefore, I marked the physical properties with alphabetical codes and the chemical properties with numerical codes. In particular, I counted each concept independently in Table 3 even though many students had more than two concepts at the same time. Table 3 indicates some of major concepts, which are in blue cells, and many students had changed their concepts of metal among these properties.

Table 3. Number of students who stated the concepts in their responses of each test (the numbers in the parenthesis are the percentage of students with n=158)

Category	Codes & Concept	Test			
		Pretest	Formative Test 1	Formative Test 2	Posttest
Physical properties of metal	A. matter that conduct (heat) and electricity	109 (68.99)	93 (58.86)	18 (30.58)	77 (48.73)
	B. matter that has malleability and ductility	80 (50.63)	53 (33.54)	19 (12.03)	37 (23.42)
	C. matter that has metallic luster	50 (31.65)	18 (11.39)	14 (8.86)	45 (28.48)
	D. matter in a solid state at room temperature	19 (12.03)	4 (2.53)	2 (1.27)	21 (13.29)
	E. matter that has free electrons	13	0	0	17
	F. matter that is dense and hard	0	3	1	13
	G. matter that has crystal structure of atoms	7	0	0	4
	H. matter that has magnetism	2	0	0	0
	I. matter that is like iron	5	0	0	0
	Subtotal Number of Responses	285	171	54	214
Chemical properties of metal	1. elements that readily lose electrons to form cations	10 (6.33)	22 (13.92)	63 (39.87)	45 (28.48)
	2. elements that has metallic bond between cations and free electrons	11 (6.96)	0	0	19 (12.03)
	3. elements that are likely to be oxidized (rusted)	8 (5.06)	32 (20.25)	40 (25.32)	21 (13.29)
	4. elements that react with acids generating hydrogen gas	10	0	61	15
	5. elements that react with water generating hydrogen gas	0	14	1	4
	6. elements that are placed at the lower left on the periodic table.	1	0	0	2
	7. cations that are solidified	0	0	0	2
	8. elements that are strongly reactive	0	18	0	2

	9. elements that have strong reducing ability	0	4	31	1
	10. elements become basic when dissolved in water	0	61	0	0
	Subtotal Number of Responses	40	151	196	111

Then I created Figure 2 and 3 to see the overall changes in distributions of the students' concepts.

Figure 2. Change of the concepts about the physical properties with Tests

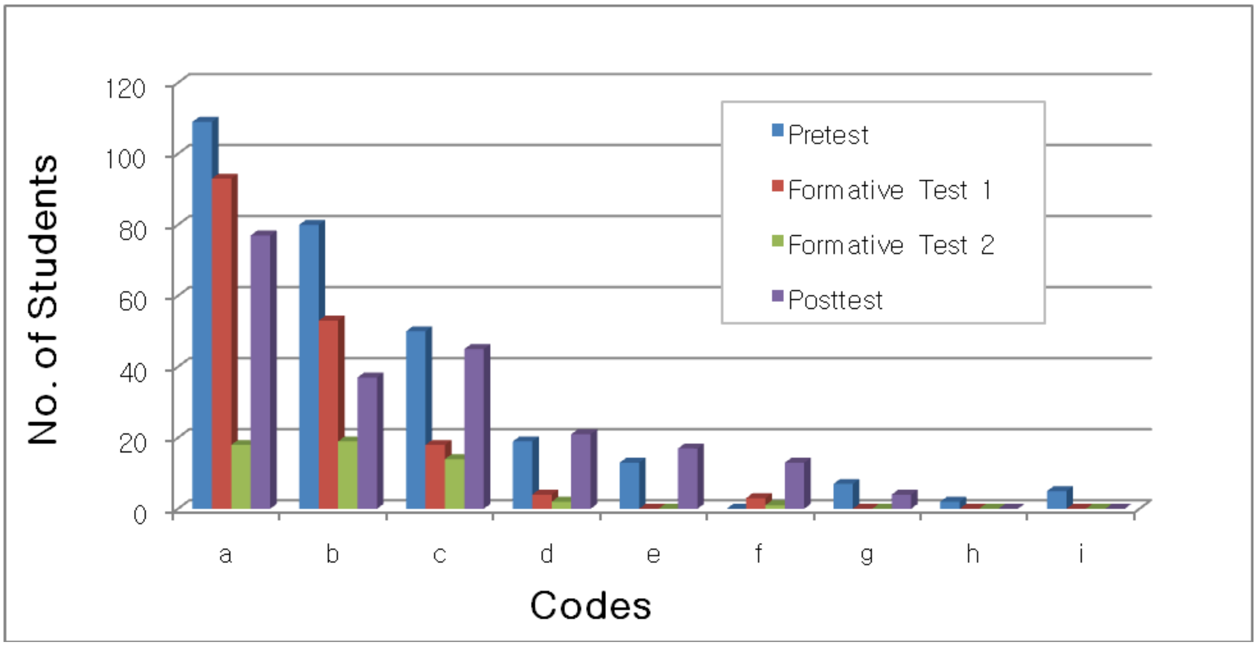
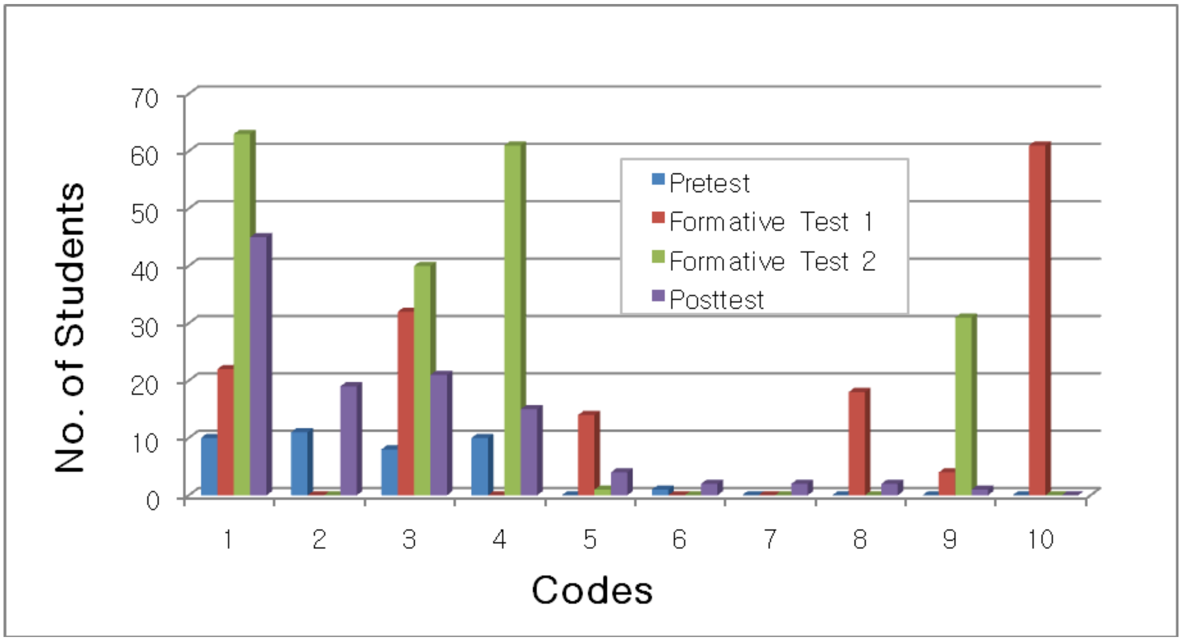


Figure 3. Change of the concepts about the chemical properties with Tests



As the students conducted laboratory activities, the kinds and distributions of the concepts changed significantly (see Table 3 and Figure 2 & 3). New concepts emerged, and some of old concepts disappeared as students learned through the activities. In particular, the chemistry concept 4, 5, 8, 9 and 10 in Table 3 were dominant in specific tests (Formative test 1 or 2) because these concepts were from particular results of the experiments in Activity 1 and 2 (see Table 3 and Figure 3).

However, I found seven big concepts of metals important from Table 3 and Figure 2 & 3 and listed in Table 4. This time I changed the category names of the concepts. The big four physical properties are named as "preconceptions" because they were prior knowledge the students held before the unit. The big three chemical properties are named as "target concepts" that I wanted the students to learn through the activities.

Table 4. The big seven concepts that the students had in their responses

Category	Coded concepts	% of students in the pretest
Preconceptions	A. matter that conduct (heat) and electricity B. matter that has malleability and ductility C. matter that has metallic luster D. matter in a solid state at room temperature	72.15
Target conceptions	1. elements that readily lose electrons to form cations 2. elements that has metallic bond between cations and free electrons 3. elements that are likely to be oxidized	15.82

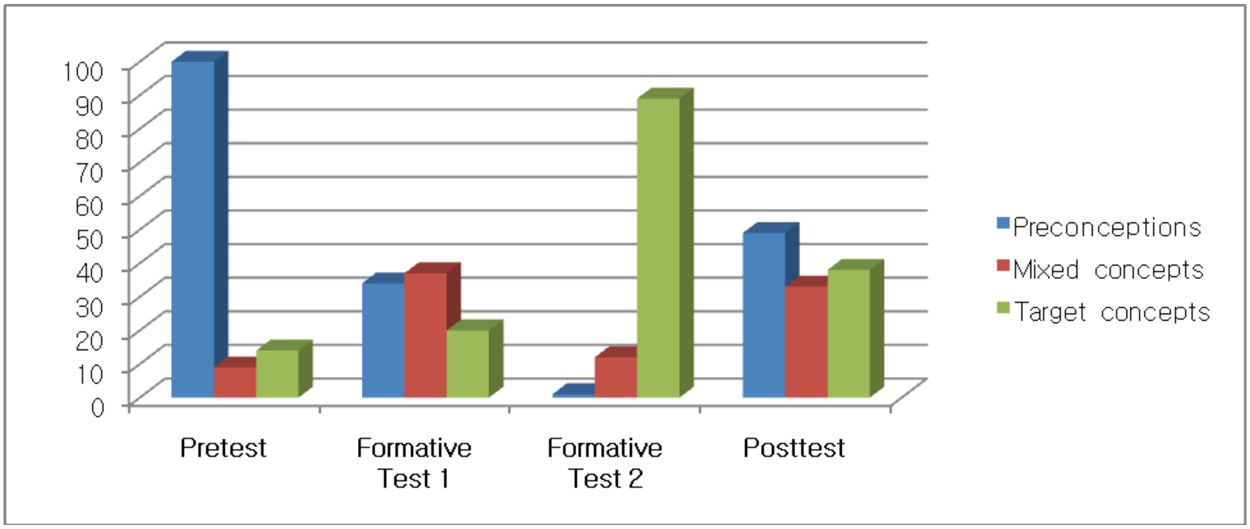
Analysis of students' conceptual change with the learning activities

In order to monitor the conceptual change of the students over time, I analyzed the data with the big seven concepts in Table 4. Table 5 shows the changes in the numbers of students who had the big seven concepts in each test.

Table 5. Numbers of students who had the big seven concepts in each test

Category	Description	Test			
		Pretest	Formative Test 1	Formative Test 2	Posttest
Preconceptions	# of students who had only the concepts about physical properties of metals	100	34	1	49
Mixed concepts	# of students who had both the preconceptions and the target concepts	9	37	12	33
Target conceptions	# of students who had only the concepts about chemical properties of metals	14	20	89	38

Figure 4. The overall view of conceptual change process



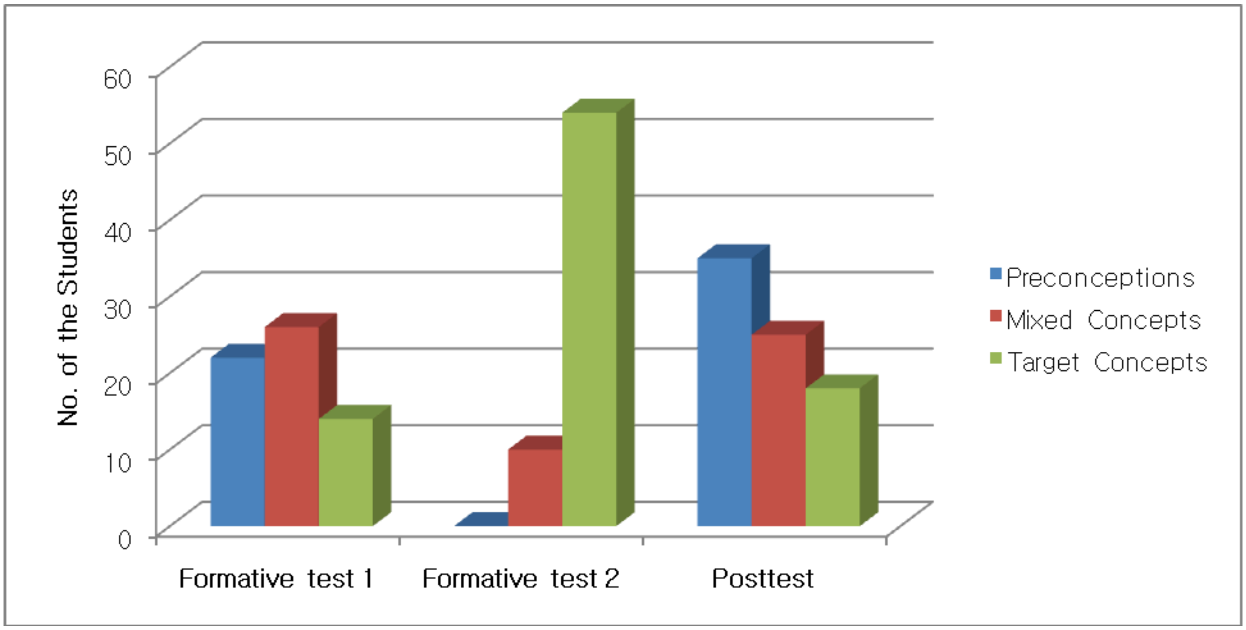
To find out how the 100 students, who had only the preconceptions in the pretest in the yellow cell in Table 5, changed their concept as they conducted each activity, I followed up their changes using the Filtering function of Ms Excel.

Table 6. Evolution of 100 students who had only off the target concepts in the pretest

Category	Description	Test		
		Formative Test 1	Formative Test 2	Posttest
Preconceptions	# of students who had only the concepts about physical properties of metals	22	0	35
Mixed concepts	# of students who had both the preconceptions and the target concepts	26	10	25
Target concepts	# of students who had only the concepts about chemical properties of metals	14	54	18
Total number of student		62	64	78

In Table 6, the numbers of students who had only the preconceptions are reduced, and the numbers of students who developed the target concepts are increased. In other words, as the students learned about metal from the activities, their concepts changed from the preconceptions to the target concept, but not directly. Moreover, I found "backslide" of the conceptual change in the delayed posttest in Figure 5.

Figure 5. Evolution of 100 students who had the Preconceptions in the pretest



Besides, the total number of the students in each test in Table 6 was always less than 100, which was the original number of students in the pretest. The rest of students took the other learning paths to other chemical properties which are mostly about factual knowledge from the experiments.

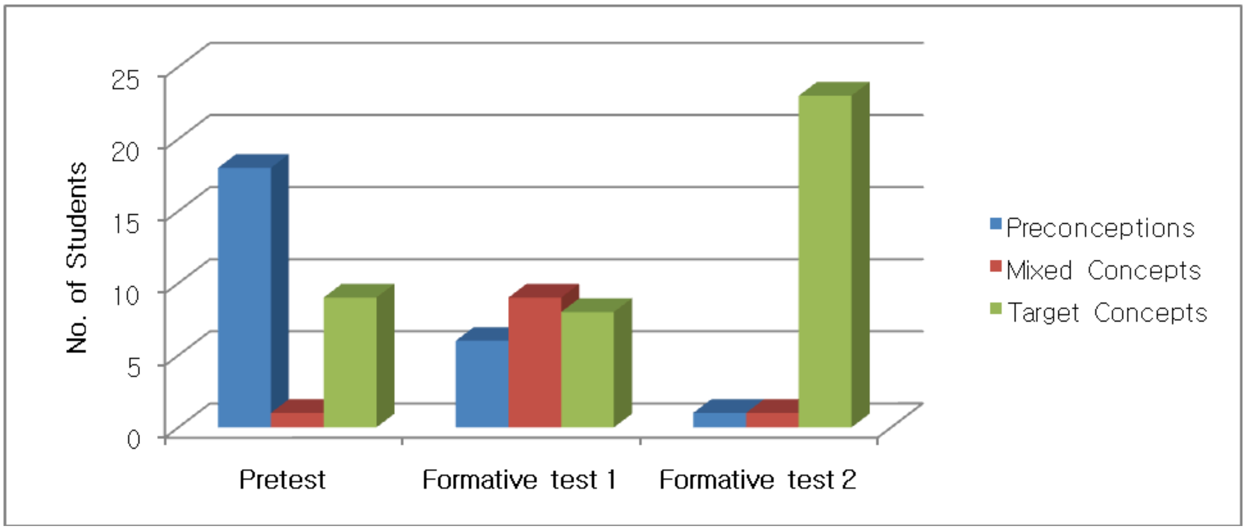
I also analyzed in Table 7 and Figure 6 the 38 students who had only the target concepts in the posttest to check where they came from.

Table 7. Evolution of 38 students who had only chemistry concepts in the posttest

Category	Description	Test		
		Pretest	Formative	Formative

			Test 1	Test 2
Preconceptions	# of students who had only the concepts about physical properties of metals	18	6	1
Mixed concepts	# of students who had both the preconceptions and the target concepts	1	9	1
Target concepts	# of students who had only the concepts about chemical properties of metals	9	8	23
Total number of students		28	23	25

Figure 6. Evolution of 38 students who had only target concepts in the posttest



18 of the 38 students had only the preconceptions in the pretest, and 23 of the 38 students have built the target concepts by the time Formative test 2 was administered. In Formative test 1, the number of students who were in the stage of mixed concepts increased substantially.

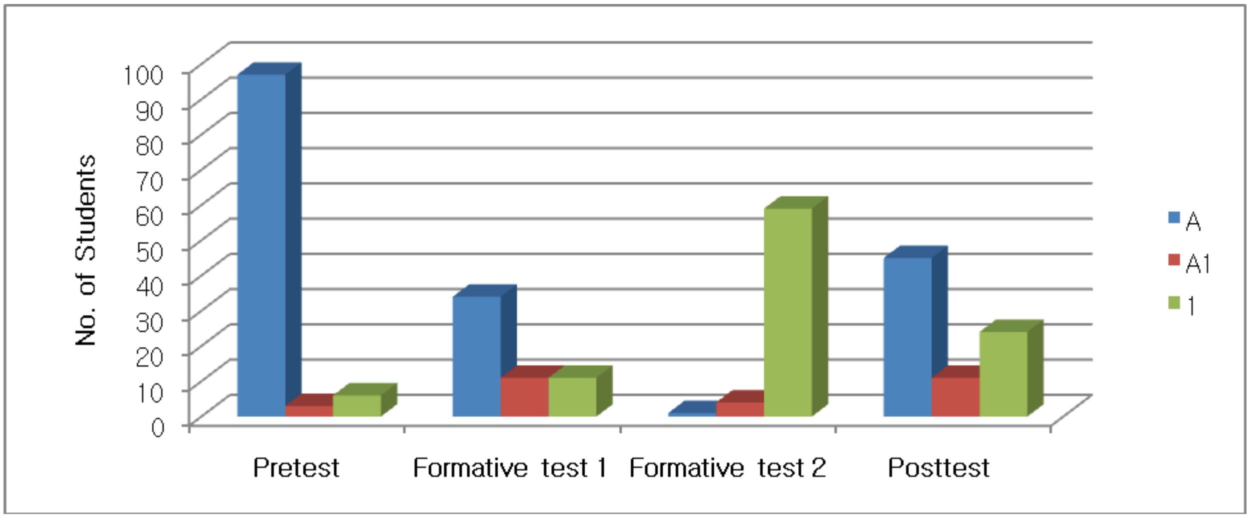
Deep analysis of students' conceptual change with the learning activities

Table 8. Number of students who stated the Concept A or 1 in each test

Category	Description	Test			
		Pretest	Formative Test 1	Formative Test2	Posttest

A	# of students who had only concepts about physical properties with Concept A	97	34	1	45
A1	# of students who had both Concept A and Concept 1	3	11	4	11
1	# of students who had only the concepts about chemical properties with Concept 1	6	11	59	24

Figure 7. Distribution of Concept A, A1, and 1 in each test



Besides, I recounted the numbers of students with regard to only Concept A and Concept 1 in each test in Table 8 and Figure 7 because I found that students who had the Concept A in the pretest also stated at least one of the Concepts "B", "C" and "D" (see Appendix D) and the Concept "1" was the overarching concept under which other concepts are connected.

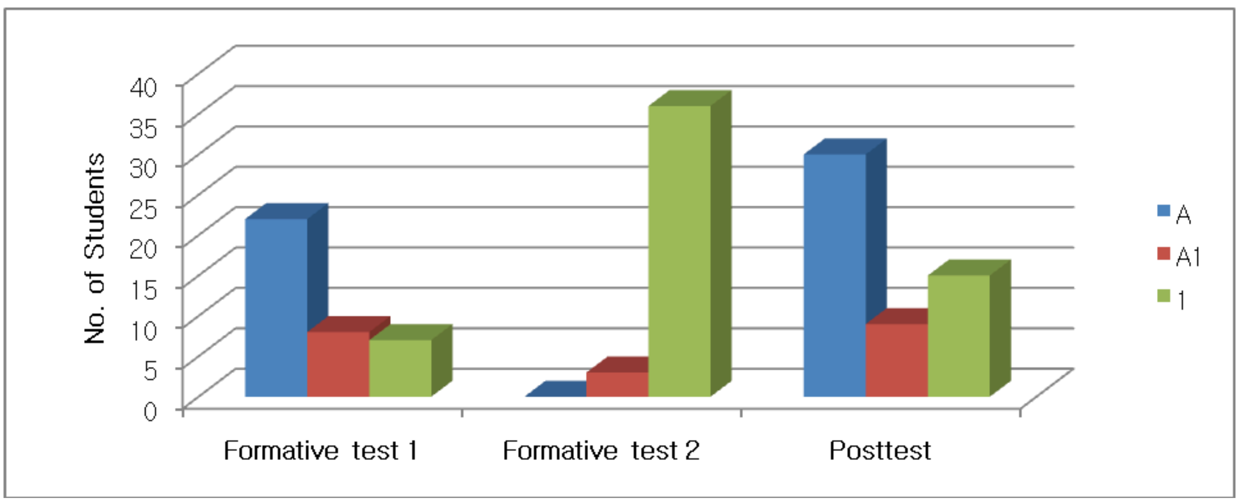
Then, in order to see the evolution of students' concepts about metal from another point of view, I selected 97students who had only concepts about physical properties of metals and Concept A, and then tracked down their changes over time in

Table 9 and Figure 8.

Table 9. Conceptual change of 97 students of the pretest

Codes	Description	Test		
		Formative Test 1	Formative Test 2	Posttest
A	# of students who had only concepts about physical properties of metals with Concept A	22	0	30
A1	# of students who had Concept A and Concept 1	8	3	9
1	# of students who had only the concepts about chemical properties of metals with Concept 1	7	36	15
Total number of students		37	39	54

Figure 8. Conceptual change of the 97 students of the pretest



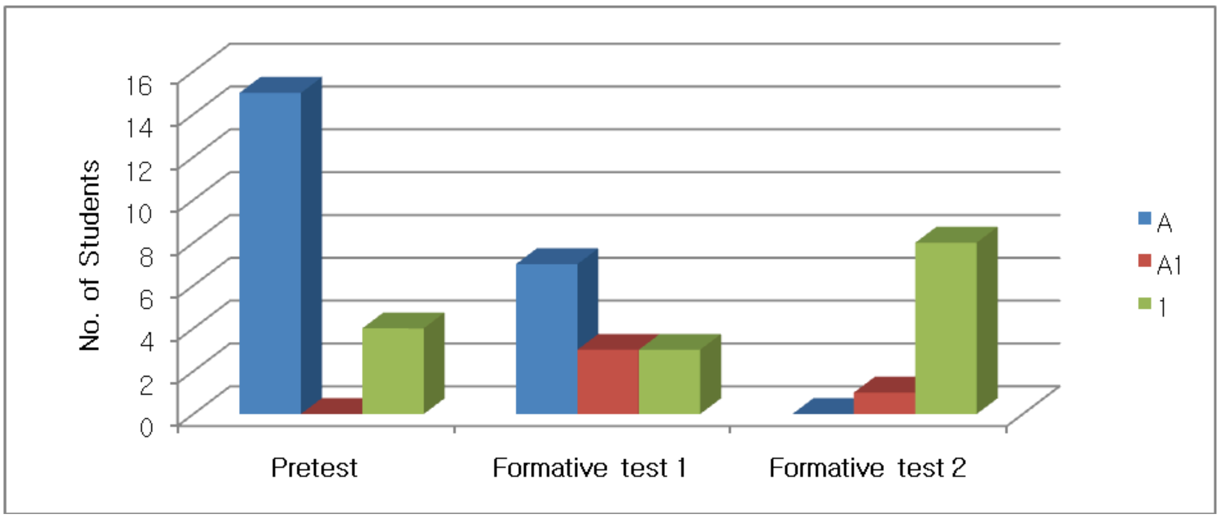
In addition, to find out where Concept 1 in the posttest came from, I selected the 24 students who had only concepts about chemical properties and Concept 1 in the posttest and followed their changes in Table 10 and Figure 9.

Table 10. Conceptual change of 24 of the posttest

Codes	Description	Test		
		Pretest	Formative Test 1	Formative Test 2

A	# of students who had only concepts about physical properties of metals with Concept A	15	7	0
A1	# of students who had Concept A and Concept 1	0	3	1
1	# of students who had only the concepts about chemical properties of metals with Concept 1	4	3	8
Total number of students		19	13	9

Figure 9. Evolution of concepts of students who had only chemistry concept 1 in the posttest



I found the same pattern as I found from the analysis of the big seven concepts (see Figure 4, 5 & 6 for comparison). Nonetheless, one thing different is that the number of students who changed from Concept A to Concept 1 was lower than that of students who changed from off the target concepts to the target concepts. Only about 40~50% of 97 students were involved in the learning path from Concept A to Concept 1 in each stage.

Effectiveness of Inquiry-based Laboratory for Conceptual Understanding

I examined with the test results and students' survey how effective the inquiry-based laboratory activities were. Especially, in terms of conceptual understanding, I tried to find out the strengths and limitations of inquiry laboratory to improve this strategy in the future.

Students' achievement of the learning objectives in the laboratory activities

In order to find out the achievement of students' learning objectives of each activity, their responses to the four subquestions as formative tests on the lab worksheets as well as the result of their summative test were analyzed by using the Excel program.

First, the students' concept about alkali metals' occurrence in the nature was measured with the questions: what kind of particles does sodium in salt crystal exist as? Why can we not find out alkali metal as a metallic form in the nature? The results are Table 11 and 12.

Table 11. Analysis of students' concept about alkali metal

Response	# of students	% of students
Ion	124	78.48
Atom	0	0.00
Molecule	17	10.76
Blank	17	10.76

About 80% of the students perceived exactly the particle form of alkali metal in compounds. Some of students thought that alkali metal elements in compounds exist as molecular form because they consist of compounds. Some of students who chose molecule explained that salt crystal cannot conduct electricity because they don't have ions in the crystal. However, many students understood exactly why alkali metals don't exist as pure elements (see Table 12).

Table 12. Students' explanations about alkali metal's occurrence

Students' conception	# of Students	% of Students
They are highly reactive (to oxygen and water) that they form compounds.	133	84.18
They are likely to be oxidized.	16	10.13
They are likely to lose electrons to form stable cations.	33	20.89
They are dissolved in water.	29	18.35

Second, the students should learn how to compare metal's reactivity from the unit. For this goal, Activity 3 was conducted, and their concepts about the reactivity order were examined in Table 13.

Table 13. How can metal's reactivity order be decided? (The numbers in parenthesis are numbers of students who also had the concept A in their responses.)

Code	Students' concept about metal's reactivity order	# of students	% of students
A	The vigorousness of hydrogen gas evolution when metals react with acids or water	80	50.63
B	The ease of metals' oxidation by losing electrons to become cations	80 (19)	50.63
C	The reaction rate of oxidation by air or water	1 (1)	0.63
D	How fast metals dissolve into the salt solution	30 (15)	18.99

The interesting finding is that two concepts were competing: Concept A and B. 19 students who had concept A had concept B as well, which means only 38.85%

students had concept B instead of A. In chemistry, Concept B is higher level of concept of oxidation than Concept A.

Third, in activity 3, the students carried out an experiment to find out and compare the nature of alloy and plated metal using copper and zinc. As a result, 100% of students believed that plated metal was a heterogeneous mixture of metals in which a metal was covered with another metal keeping their own properties, whereas the alloy of two metals was believed to be a compound rather than a homogenous mixture because it had totally different properties from the original metals.

Last, the students learned about the reasons and ways of protecting metal from corrosion in Activity 4. 58.23% of the students had the concept of oxidation as a combination of matter with oxygen. Only 13.92% of the students in Table 14 showed the higher level of oxidation by which matter lose electrons.

Table 14. What causes the corrosion of metal?

Concept	# of students	% of students
Contact with oxygen and water	4	2.53
Oxidation by oxygen	92	58.23
Ease to be oxidized	33	20.89
Reactivity to lose electrons	22	13.92
No response	7	4.43

Table 15. Achievement of the objective of each activity on the formative tests

	# of Students who got correct answers	% of Students who got correct answers
Activity 1	133	84.18
Activity 2	156	98.73
Activity 3	157	100
Activity 4	147	93.04

In short, the objectives of each activity were achieved by more than 80% of students.

On the other hand, in the summative test (Table 16), the students also showed average 90.11% of understanding of content from each activity.

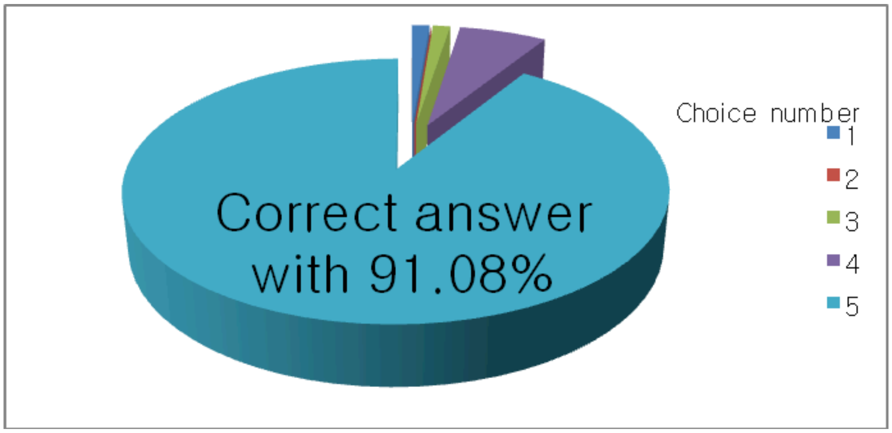
Table 16. Students' achievement on the summative test

Item Number	Tested Content	Related activity	Type of Reasoning	% of correct answer	Item Difficulty
1	Concept of metal	all	Knowledge	91.70	low
2	Metal' chemical properties	all	Comprehension	86.72	middle
3	Alkali metal's properties	Activity1	Comprehension	84.13	middle
4	Reactivity order of metal	Activity 2	Application	95.11	high
5	Alloy and plating	Activity 3	Comprehension	88.02	middle
6	Corrosion of metal	Activity 4	Application	94.98	high
average				90.11%	

Efficiency for conceptual understanding

In addition, 91.08% of students on the summative test in Figure 10 selected Concept 1 (choice 5) instead of Concept A (choice 1) (see Appendix C).

Figure 10. Students' concept about metal on the summative test



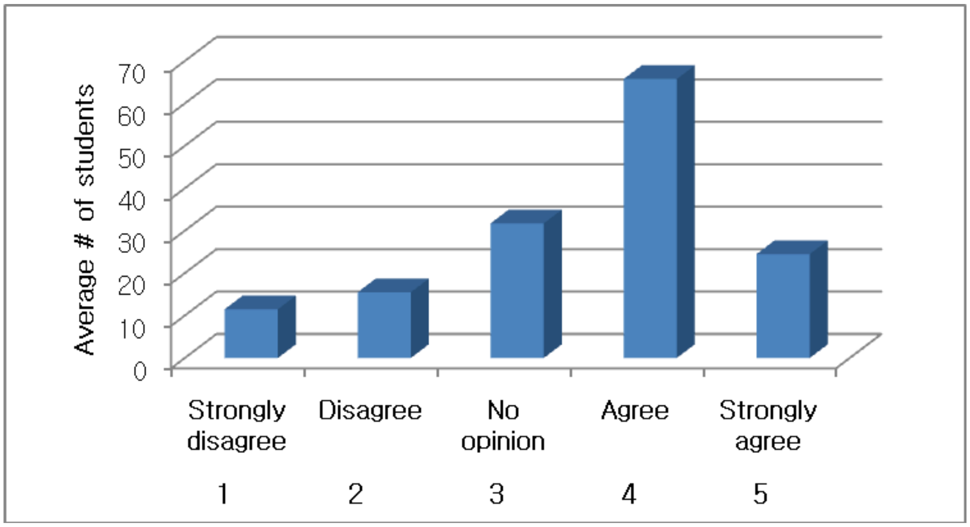
Students' perceptions toward the effectiveness of the inquiry laboratory

When the students were asked to evaluate the statement "I learned a lot about the concepts from each activity." by using Likert scale, their average perception about the efficiency of each activity for conceptual understanding was 3.46, which is a little positive (see Table 18 and Figure 11). Particularly, activity 1 and 4 seem to be easier to understand than Activity 2 and 3.

Table 17. Students' perception about effectiveness of each activity for conceptual understanding

Scale	Description	# of students				Average # of students
		Activity 1	Activity 2	Activity 3	Activity 4	
1	Strongly disagree	9	7	16	14	11.5
2	Disagree	18	28	22	14	15.5
3	No opinion	26	48	32	21	31.75
4	Agree	77	56	61	69	65.75
5	Strongly agree	24	15	23	36	24.5
Average rating		3.58	3.29	3.34	3.64	-
Mean of average ratings		3.46				-

Figure 11. Students' perception about effectiveness of activities for conceptual understanding



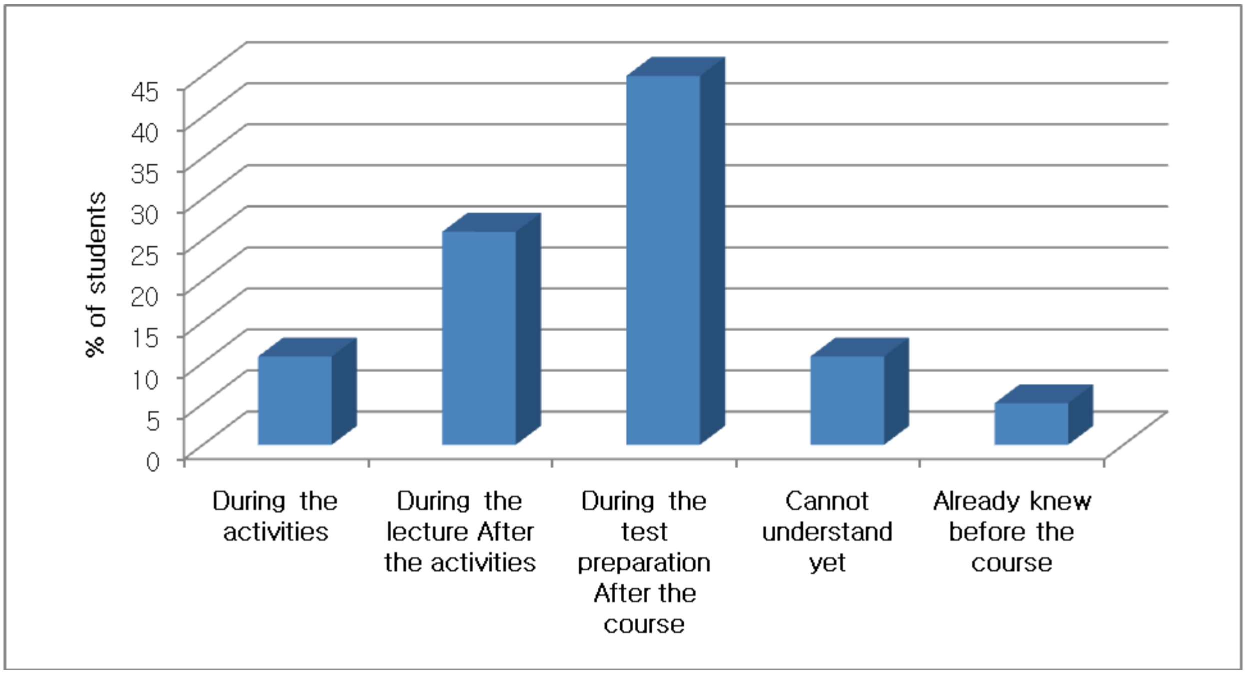
Time when conceptual understanding occur

The students were asked to give responses in the survey about the time when conceptual understanding took place. Only 10.76% of the students in Table 19 and Figure 12 believed that they understood the activities while they were conducting experiments.

Table 18. Students' perception about the time when conceptual understanding took place

Choice	# of students	% of students
During the activities	17	10.76
During the lecture After the activities	41	25.95
During preparation for the midterm test After the course ended	71	44.94
Cannot understand yet	17	10.76
Already knew before the course	8	5.06

Figure 12. When did conceptual understanding take place?



Students' perception about the strengths of inquiry-based laboratory

When the students were asked to make statements about the strengths of inquiry-based laboaratory that they experienced in this project, they answered like the following Table 20.

Table 19. Students' perception toward strengths of inquiry-based laboratory

Code	Description	# of Students	% of Students
understanding	Foster understanding	54	35.06
experience	Have first-hand, concrete experience	48	31.17
motivation	Induce the need to know	40	25.97

memory	Help retain memory longer	15	9.74
participation	Active participation and learning	11	7.14
proceed	Make rapid proceed of class	3	1.95
reasoning ability	Foster the scientific reasoning ability	1	0.65
skill	Learn the skill to perform experiments	1	0.65
blank	No response	27	17.53

The most important strength was that inquiry-based laboratory helped the students understand the topics. Secondly, they thought of the laboratory as very useful, for they had new and first-hand experience which helped them motivated and understand chemistry. The third place of strength was motivation, which induced the need to know in their minds.

Students' perception about the limitations of inquiry-based laboratory

The students also pointed out the limitations of the laboratory instruction. Ironically, 44.16% of students in Table 21 said they couldn't understand the procedure or make sense of data although they thought of the most strength of inquiry laboratory as helpful for understanding in Table 20.

Table 20. Students' perception toward the limitations of inquiry-laboratory

Code	Description	No. of Students	% of Students
Hard to grasp the meaning of activity	• It required preview of the purposes and the underlying principle of activities to perform the activities. • Some activities produced unclear results or data leading to wrong conclusions. • Making sense of experiments requires much background knowledge. • Some data analysis requires help or explanation from the teacher. • The procedures were too complex to follow and understand.	30 19 11 6 2	44.16%
Hard to manage the classroom environment	• Some students didn't participate in the group activities. • It was hard to concentrate due to disorder or chaos. • It might cause accidents.	20 7 4	20.13%
The activities were inefficient to learn.	• Lack of time to finish the work in a 50 min. class time. • They were more time consuming work than class lecturing. • The summative test was irrelevant to the activities.	27 2 1	19.48%
Troublesome & bothering	• I just wanted to hear a lecture sitting down.	10	6.49%

Discussion

My action research project examined 158 Korean 11th grade students' conceptual development about metal in the subject Chemistry I as they conducted inquiry-based laboratory activities of the unit Metal. This paper also assessed the strengths and limitations of the inquiry laboratory for students' conceptual change.

Summary of Findings

With regard to the first research question - How did the students' concepts of metal evolve through guided inquiry-based laboratory activities? – I found the following facts.

1. Students had strong and abundant prior knowledge which were mostly about metals' physical properties without understanding of metallic bond before the unit began to be taught. 100 out of 158 students had the preconceptions (Concept A, B, C, & D) in the pretest (see Table 3 & 4).
2. I found a major learning path of the unit Metal from the preconceptions of big four physical properties to the target concepts of big three chemical properties (see Table 5 and Figure 4).

3. In addition to the major learning path, there seems to be diverse learning paths the students took when they tried to develop the concept of metal (see Appendix D).
4. In the first stage of Activity 1 when Formative test 1 was taken, the students began to obtain the chemical properties from the experiments. This stage seems to be a transitional step from the preconceptions to the target concepts.
5. In the second stage of Activity 2 when Formative test 2 was conducted, most of the students replaced their old preconceptions with the new target concepts.
6. In the delayed posttest, I found backslide of conceptual change. 49 students reverted to the preconceptions; 33 students kept both the preconceptions and the target concepts; and 38 students maintained the target concepts as the definition of metal.

In terms of the strengths and limitations of the inquiry-based laboratory for the students' conceptual understanding, I found the following things.

- The inquiry laboratory helped the students obtain factual knowledge which were the learning objectives of the activities. 94% of the students on average gave correct answers on the four formative tests and 90.11 of the students on average chose the correct answers on the summative tests. The students explained that the activities allowed them to have new first hand experiences, and thereby to be motivated to participate in the learning activities that they were able to understand the new knowledge.

- The inquiry laboratory was ineffective to promote the conceptual understanding given the fact that they failed to build a well-organized conceptual structure under the overarching concept (Concept 1). Many students didn't realize the priority of their concepts about metal. As a result, they stated not only Concept 1 but also other factual chemical properties as a definition of metal from a chemist's perspective (see Appendix D). Only 38 out of 158 students realized the overarching concept until Activity 2 was finished. Moreover, 19 students maintained the desirable conceptual structure by the time the delayed posttest was taken. According to the students' explanation, they didn't understand the meaning of the series of activities. They had to have more background knowledge for the activities. They needed more time to discuss the meaning with the teacher.

Explanation and Conclusion

Students' prior knowledge about the concept of metal

The students' preconceptions were about metal solids' physical properties such as conductivity of electricity, metallic luster, ductility, malleability and hardness. What is interesting is that Concept A, which is a concept of metal as conductor of electricity, was the dominant concept that came together with other preconceptions. These are informal understandings of metals from people's common sense which have some truth to them. However, to chemists, metals are defined as a group of elements that readily lose electrons to form cations in their chemical reactions and have metallic bonds among metal atoms (Metal, 2008). Atoms in a metal have delocalized valence electrons which give rise to metal's physical and chemical properties. However, 68.99% of the participants of the pretest believed that metals were a group of "matter", not elements, that can conduct electricity (see Table 4). Scientifically, the idea of matter that can conduct electricity is a definition of conductor, not metal. Of course, all metals are conductors of electricity. Nonetheless, there are so many kinds of non-metal matter that are conductors of electricity such as plasma, graphite, doped semiconductors, and aqueous solutions of electrolytes. Therefore, the participants' concept of metal as a conductor of electricity was a problematic concept, which was a serious obstacle to learn chemistry. Their concepts of conductor needed to be differentiated (Driver at al., 1993).

Where did the students get these ideas? They acquired the preconceptions from their daily lives and previous formal education. When they were in elementary school, their learning about metal just was centered on its physical properties in order to learn how to classify matter according to its properties. Thus, they came to conceive that metals are conductors and nonmetals are insulators except graphite. In addition, they had experienced all electric wires are composed of copper or other metals. They had seen all metals shining because metals' surface reflects visible lights. They had known that metals are easy to shape into diverse forms because of metals' ductility and malleability. However, they didn't have enough experience to see metal's chemical change but rusting of iron. Consequently, their prior knowledge limited to the physical properties of metal.

Taber (2001) explained problems concerning prior knowledge as deficiency, fragmentation, and pedagogic learning impediments. Deficiency learning impediment can be cured by providing students with more new experiences to increase the amount of knowledge. Thus, my instructional activities were intended to introduce new ideas about metals' chemical properties to the students. Fragmentation learning impediment should be treated by integrating existing ideas with presented ideas (Driver et al., 1993; Taber, 2001). So, my instruction sought to make connections between their preconceptions with the target concepts. Solving the pedagogic impediment was attempted by expanding the students' limited concepts of conductors and oxidation to more general ones as the students made progress in chemistry learning.

The most important feature of the preconceptions is that they are not wrong concepts, but naïve intuitive ideas. diSessa called these intuitive ideas phenomenological primitives (p-prims for short) as minimal abstractions of simple common phenomena. The preconceptions as p-prims were fragmented factual knowledge that are required as elements to build an organized coordination class under the overarching concepts of higher priority to make their conditions of activation sophisticate.

In summary, from the analysis of their prior knowledge in the pretest, I found the dominant preconception, metals are the matter that can conduct electricity, which needs to be differentiated and restructured under the concept of metallic bond. Furthermore, the participants needed to acquire the concepts about metals' chemical properties and to build understanding of the overarching concept (Concept 1) as the fundamental cause of those properties.

Conceptual evolution through the activities

Over time, the students abandoned the preconceptions and acquire the target concepts through the activities (see Figure 2 & 3). However, the process was slow and the posttest indicated the students didn't forget the preconceptions (see Table 5 and Figure 4).

The analysis of conceptual changes with the big seven concepts indicated that the students in the stage of Activity 1 when Formative test 1 was taken seems to a transition state from alternative to chemistry concepts given the fact that they kept their old ideas and attained new ideas as well. The students just started to realize that their idea of metal as a conductor could help them explain only one of physical properties and could not help them understand chemical properties of alkali metals.

Alkali metals' strong metallic character provided the students with discrepant events. Potassium is soft and melts at low temperature. Sodium reacts with water vigorously generating hydrogen gas. I gave them a hint that alkali metals are a typical example of metals from the viewpoint of chemists. Although they faced these discrepant events, only 14 students replaced their old concepts with the target concepts, and 60 students didn't develop any target concept (see Table 6 and Figure 5). This result is consistent with Chinn and Brewer's (1998) assertion that it is not enough for science instruction simply to inform students of scientific conceptions because students in many cases do not necessarily bring about the cognitive conflict through merely experiencing a discrepant event. The cognitive theory of constructivism offers an explanation of 26 students in the transition state, calling this state "assimilation" or "knowledge capture", which is not a genuine conceptual change, but just a knowledge increase. Besides, the low rate of change may indicate the difficulty of students developing general ideas from their discovery learning. I'll discuss this later in the section of inquiry-laboratory.

However, in the stage of Activity 2 when Formative test 2 was administered, none of the students stated the preconceptions as a definition of metal; 54 out of 100 students developed one of the target concepts, and 10 students were in the transition state. The accumulation of learning experiences seems to have helped students make progress in their conceptual development. The design quality of Activity 2 also may affect the speed of conceptual change. Activity 2 was about single displacement reactions of metals with metals' salts to determine the reactivity order of metals. So, it was very obvious to realize the target concepts.

Nonetheless, the analysis of the result in the posttest also revealed again the reversion of the conceptual change.

Similarly, when I traced in a backward way the conceptual change of 38 students who stated only the target concepts in the posttest, I found a similar pattern to the analysis in a forward way (see Table 7 and Figure 6).

Of special interest is that total numbers of students in three categories in each activity were always less than the original number of students in both analyses. This indicates that there were so many learning paths. Students didn't directly exchange the preconceptions with the target concepts. Some of them gained new concepts about chemical properties such as Concept 4, 5, 6, 7, 8, 9, and 10 instead of Concept 1, 2, and 3 (see Appendix D). However, about 70% of 100 students followed the path directly from the preconceptions to the target concepts. This indicates that the big seven concepts (see Table 4) are the major concepts that characterize the conceptual learning of the unit Metal. Of course, there were many students who had one of the target concepts along with the other concepts.

On the other hand, as I mentioned above, the dominant preconception was Concept A that accompanied the rest of preconceptions, and the overarching concept was Concept 1 that was the desired learning outcome in my instruction. With this idea in mind, I focused my second analysis of conceptual development on the change of 97 students who had Concept A and none of the chemistry concept in the pretest and the evolution of 24 students who had Concept 1 and none of the preconceptions in the posttest (see Table 8 and Figure 7). Not surprisingly, the pattern was very similar to the first analysis with the big seven concepts.

Nonetheless, one thing different is the percentage of students who followed the learning path from Concept A to Concept 1 was lower than the percentage of students who followed the learning path from the preconceptions to the target concepts. Only about 40~50% of 97 students involved in the learning path from Concept A to Concept 1. This result implies two things: one is that Concept A was the leading preconception; the other is that the students didn't fully understand the overarching concept, Concept 1. As a result, majority of 97 students underwent conceptual change from Concept A toward the other concepts.

In general, these patterns of the students' conceptual development demonstrated that the students made conceptual changes step by step as they experienced each laboratory learning activity, but they were not successful in terms of the quality of conceptual understanding. The students' conceptual structures were not organized as well as I expected, given that they stated the target concepts "and" the other concepts with the same priority. They didn't make fine mental links between factual knowledge and the underlying principles (Wiggins & McTighe, 2005). With the learning activities, while the multiplicity of their knowledge was improved because p-prims about metals' physical properties were differentiated and p-prims about metals' chemical properties were increased, the systematicity was not fully achieved since many of the students failed to generalize their factual learning from the activities and to realized the structure of knowledge although all activities were for the construction of the target concepts. Besides, the students regarded the target concepts as intelligible, plausible, and fruitful in making sense of their data from the experiments, yet the conceptual change was not radical but evolutional.

In sum, as diSessa (2001) contended, the students' conceptual change was a slow revision of an initial conceptual system through the gradual incorporation of elements of the scientific explanations, and there were many learning paths from students' prior knowledge to the science concepts. Moreover, the posttest result proves the tenacity of preconceptions. They were not forgotten but hidden because of the explicit learning objectives.

Instructional Implications

Inquiry laboratory can be employed to achieve such diverse goals as investigation method, technical skills, and nature of science, but my goal was to promote conceptual understanding by providing opportunities to learn by doing. The students were expected to build their knowledge from the analysis of their experiment data. Therefore, I will reflect on the method of inquiry laboratory as a teaching method for conceptual understanding.

Efficiency of Inquiry laboratory for the students' learning of content knowledge

As I mentioned earlier, I was suspicious about students' ability to learn through inquiry laboratory because neither I as a teacher nor my students had tried this before the project. So, achievement of the learning objectives was closely tested with the summative test and the subquestions in their lab worksheets as formative tests. Especially, I paid much of my attention to the formative tests so that I could make a judgment whether or not their learning took place "during" the activities. The results of their learning about the content knowledge through inquiry laboratory made me confident about the students' ability to learn by doing.

The students' perception toward the effectiveness of laboratory in assisting conceptual learning was also very positive (see Table 17 & 19 and Figure 11). The strengths mentioned in the students' survey offer an explanation of the factors that made the content learning successful (see Table 19). The most important merit of the inquiry lab was that it fosters understanding. New experiences motivated them to actively participate in the learning process to understand and remember what they learned. They also directly stated in the survey that inquiry-laboratory facilitated their understanding by allowing them to have first hand experiences.

Therefore, I came to a conclusion that my design of inquiry-based laboratory was successful at least to guide the students to attain knowledge and skills that are necessary elements of conceptual understanding.

Efficiency of Inquiry laboratory for the students' conceptual understanding

Although the students successfully acquired the elements for the conceptual understanding from the activities, many of them didn't achieve the ultimate goal of the instruction, their conceptual understanding.

Why was the instruction not successful to achieve conceptual understanding? This demonstrates a significant limit of inquiry laboratory as discovery learning. Although the students were able to analyze the data and derive simple conclusions to build the content knowledge (or p-prims about metals' chemical properties), the target concepts should be derived from the generalization of those p-prims. However, the knowledge processing of generalization required the students' effort to seek for the overarching concept from apparently fragmented factual knowledge. Obviously, many of the students didn't try to find out the target concepts and prioritize their knowledge. According to Chan, Burtis and Bereiter (1997), the level of knowledge processing activity exerts a direct effect on conceptual change. In other words, students' active learning attitude is importance in the process of conceptual change.

According to Wiggins and McTighe (2005), a key challenge in teaching for understanding in science education is to make the students' knowledge structure more sophisticated by revealing the fundamental principles that lie behind much seemingly apparent factual knowledge. To get students beyond assimilation of new factual knowledge, the inquiry activities should demonstrate to students that they need to actively induce, make sense of, verify and reflect on the content knowledge through inquiries and construction. The one thing that I regret is that the students didn't have the opportunity to discuss their learning from the experiment data with the teacher. They talked with their classmates about the data and conclusion, not with the teacher. The teacher was so afraid that her intervention might have affected my research. Another reason for not giving the opportunity to discuss was the lack of time. In 50 minutes, it was impossible to finish the experiments and discuss. Therefore, I recommend that teachers should have discussion with the students when the laboratory is finished so as to guide or scaffold students' knowledge construction. Teachers are expert in their teaching area that they need to provide their students insights.

In addition, the students' opinion for the limitations accounts for the failure. The students pointed out that it was "hard to grasp the meaning of activity" (see Table 30). They demanded to have more background knowledge before the laboratory in order to perform and make sense of the activities. They felt anxiety about the activities. The students were so accustomed to being given the directions and the rubric for their assessment before the laboratory that inquiry-method made them worry about whether or not they were on right track or their result was correct. A student honestly expressed the difficulties of inquiry laboratory saying "When I was handed over the lab worksheet and tools for experiment, I felt like being lost." She was confronting more information than she can handle. Therefore, the teacher needs to give a minimum amount of information about the inquiry laboratory or give assignments to prepare for the laboratory activity.

To improve the inquiry-based laboratory, teachers need to consider why they want to employ inquiry teaching method. The uniqueness of the science laboratory learning environment has many merits, but the merit of learning by doing is not good enough to be a primary teaching method. A student succinctly stated, "Inquiry laboratory is good for acquiring scientific investigation skill and developing reasoning ability, but inefficient for learning content knowledge. I prefer to conduct an experiment after listening to the teacher lecture regarding the same topic to build knowledge." When I designed the laboratory activities, I sought to lead the students to recognize the need for uncoverage of knowledge they were learning, the need for rethinking (Wiggins & McTighe, 2005). It is important to analyze their experiment data to derive understanding as well as the acquisition of factual knowledge.

In addition, the quality of activity is very important in achieving better understanding because unclear results frustrate students' effort to build knowledge through data analysis. The questions used in inquiry also need to be sophisticated because they influence the quality of students' responses. For example, I asked, "How would you define metal from a chemist's perspective?" instead of "What is the chemical definition of metal?" The latter ask the students recall and deliver a factual knowledge, whereas the former require the students to reflect on and make explicit their concept of metal.

Limitations and Future Study

The most significant limitation in the research was that I was not the teacher who took the action in the classroom. Even though I provided the tools and exchanged opinions with the teacher, it was not good enough to get the feeling of the classroom. I tried to compensate this limit by having large size of participants (158 students) for the validity of my research. However, I think the fact that I was not the teacher considerably affected the results of the students' conceptual development.

For example, even though I made the six questions focusing on my inquiry-laboratory activities, the summative test result has a limitation to be direct evidence of their learning from the laboratory activities because there were other learning activities such as the teacher's lecture during the unit. To prove this I should have had a control group, but it is immoral to make a class a control group because of the equity of education. The students may have learned indirectly from those activities and self-study for the summative test. This interpretation is also consistent with the students' survey result. When they were asked to tell the time their understanding occurred, only 10.76% answered that it was during the activities while 44.94% of students replied that it was during the preparation for the summative test after the unit concluded (see Table 18 and Figure 12).

Another problem was that I could not change my plan during the actions. I intended to ask the deriving question in all four activities, but I didn't include the question in Activity 3 and 4. I should have seen the result from those activities. Besides, the posttest was not conducted immediately after the unit ended. Some research papers have two posttests: immediate and delayed. But I have only the delayed posttest.

Last but not least, the design of the laboratory activities may have affected the results. Although I am content with the results, they could have been better with more sophisticated design. So, when I go back to Korea to teach again, I will do the same thing armed with the lessons from this research and conduct more action research projects with other units.

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Appendix A

The Pre and Post Test

1. How would you define the concept of metal from a chemist's perspective?

2. What kind of particle do you think sodium in salt exist as? Choose one of atom, ion, and molecule, and give a brief explanation for your choice.

3. Explain how to determine the reactivity order of metal.

4. What is the difference between alloy and plating?

5. Why does metal's corrosion happen? And how can we protect metal from corrosion?

Appendix B

Activity 1: What are metals?

Topics of Inquiry:

- Why can we not see solids of pure alkali metals around us?
- What properties make alkali metals metals?

From now on we are going to learn Unit III. Metals and their Utilizations. Particularly, we will learn about metals' physical and chemical properties and how to use their properties in our life. Today in Activity 1, we will explore properties of alkali metals which are typical examples of metals. Alkali metals are lithium, sodium, potassium and etc that are located in the far left side of the periodic table. Let's think about the causes that make them a group of alkali metals.

1. Establishment of hypothesis: answer the following questions before the experiments.

① What properties do metals referred to as in chemistry have?

② What make alkali metals invisible as pure solids of elements?

③ What kind of particles do sodium in salt crystals exist as?

2. Procedure and Results: Follow the directions and record what you observe.

A. Physical properties of alkali metals

① In which state are lithium, sodium, and potassium in at room temperature? What does the state mean?

② How are alkali metals preserved and stored in the laboratory? Why?

③ Do lithium, sodium, and potassium metals conduct electricity?

④ Let's touch the sodium, and potassium metals with your hand. Be sure to wear a disposable plastic glove on your hand. How do you feel? Let's decide the order of three metals' density.

B. Chemical properties of alkali metals

① Let's watch the teacher cutting alkali metals with a wooden knife. You pay attention to the changes in the cutting edges. What made the changes?

② Fill a beaker half with water. Put into the beaker a small piece of lithium metals that the teacher gives you. Watch what happens in the beaker. Repeat the same process with sodium and potassium with new beakers. Which metals react with water more vigorously?

③ Add a drop of phenolphthalein solution into the water in the beaker, and observe the change in colors. What does the change tell you about the metals' properties?

④ Let's observe the teacher who collect the gas from the reaction of sodium with water. She will show you some reaction of the gas. What do you think is the gas? How does the gas evolve from the reaction of sodium with water?

3. Drawing Conclusions

① Although lithium, sodium, and potassium metals have distinctive properties, they are classified as the first group of alkali metals in the periodic table. What makes them classified as a group of alkali metals? Give some evidences from the experiments for common physical and chemical properties.

② Alkali metals are typical examples of metals. What is metallic character from the chemist's view? How would you define the concept of metal from a chemist's perspective? Think about what made them typical to find answers for the questions.

③ What properties make alkali metals invisible as pure solids of elements?

④ What kind of particles do sodium in salt crystals exist as? Why?

Activity 2. How do metals react with other chemicals?

Topics of Inquiry:

- What characterize the reactions of metals?
- How can you decide the order of reactivity of metals?

We have learned the properties of metals in Activity 1 through the experiments about alkali metals' properties. Today, we will investigate the chemical reactions of common metals such as zinc, aluminum, and copper. Metals' chemical reactions have a distinctive feature that defines metal from a chemist's perspective. Alkali metals have the strongest feature. Let's think about what metals are again. Let's decide the order of reactivity of metals.

1. Establishment of hypothesis: answer the following questions before the experiments.

① What is the common feature of metals' chemical reactions?

② Let's decide the order of reactivity of iron, copper, aluminum, magnesium and zinc. What is your criterion for the order?

③ How would you define the concept of metal from a chemist's perspective?

2. Procedure and Results: Follow the directions and record what you observe.

A. Metals' reaction with diluted acids:

Alkali metals react with water vigorously, but other metals cannot react with water. Some metals can react with diluted acids, but gold and silver don't react with diluted acids. In this activity we will experiment with some metals and diluted hydrochloric acid and make a decision about the order of reactivity.

① Prepare five test tubes with a stand, and fill a third of the tubes with diluted hydrochloric acid. Get five metal tips of iron, copper, aluminum, magnesium and zinc. Then put each metal into the tube and watch what take place in it. Put them in an order of vigorousness of the reactions. How do you know some reactions are more vigorous than others?

② Collect a gas from one test tube with a method of upper displacement. Burn the gas with a match. What is the gas? How do you know? How does the gas evolve from the reaction of a metal and a diluted acid?

B. Metals' reaction with their salts' solutions:

Compounds that have metals' cations are called salts. In this experiment, we will see the reactions of metals with their cations in chlorides' aqueous solutions.

① Prepare five 100mL beakers, and then fill them to the third with iron(II) chlorides. Put into the beakers a tip of iron, copper, aluminum, magnesium and zinc relatively. Then watch the change in the metals in the beakers. Fill the data table.

② Repeat the same process with the same metals and $AlCl_3(aq)$.

③ Repeat the same process with the same metals and $MgCl_2(aq)$.

④ Repeat the same process with the same metals and $ZnCl_2(aq)$.

⑤ Repeat the same process with the same metals and $CuCl_2(aq)$.

Salts Metals	Fe	Cu	Al	Mg	Zn
$FeCl_2$					
$AlCl_3$					
$MgCl_2$					
$ZnCl_2$					
$CuCl_2$				?	

⑥ Explain the chemical reaction for the question mark in the table.

3. Drawing Conclusions

① From the experiments that you have done, what are the common feature of the reactions?

② Let's decide the order of reactivity of the five metals. How did you do it?

③ How would you define the concept of metal from a chemist's perspective?

Activity 3. How do metals react with other metals?

Topics of Inquiry:

- How the process of plating and alloy change the properties of metals?

In Activity2, we investigated how metals react with cations of diluted acids and salts' aqueous solutions. Today we are going to observe the reaction of metals with other metals. The products of metals' reaction with other metals are plated metals and alloys. Plated metals are metals covered with another metal. Alloys are metals that are produced by homogenously mixing with other metals or other chemicals by heating. Let's explore the world of alloy and plating.

1. Establishment of hypothesis: answer the following questions before the experiments.

① copper plate and zinc powder are pure metals. What kind of particles consists of the metals? Why? Or how do you know?

② Does plating change each metal's properties or not? Do you think of a plated metal as a mixture or a compound? Explain your answer.

③ Does an alloy of two metals change each metal's properties or not? Do you think of an alloy as a mixture or a compound? Explain your answer.

2. Procedure and Results: Follow the directions and record what you observe.

A. Reactions of copper with zinc

① Pour 20mL sodium hydroxide solution into a evaporating dish and 5g of zinc powder. Then heat the mixture on an alcohol lamp.

② When the mixture is boiling, place four pieces of copper plate into the dish. When the plates are changed into silver color, take them out of the dish and rinse them with cold tab water. How do the copper plates become silver color? Explain the change.

③ Dry up two of the plates from the step of ② and place them into the flame of lamp until they become gold color. Why do the metals need to be burned in a fire to change the color? Explain the change.

B. Comparison between alloy and plating

① Let the silver and gold plates react with diluted hydrochloric acid. Observe the changes and compare the results.

② Let the silver and gold plates react with concentrated nitric acid. Observe the changes and compare the results.

3. Drawing Conclusions

In Activity 2, we've learned that zinc is more reactive than copper in a reaction with diluted hydrochloric acid. However, concentrated nitric acid is different form diluted hydrochloric acid in that it is not an acid but an oxidant that dissolves metals with low reactivity. With this information, analyze the data and answer the following questions.

① Why does copper have different properties from zinc?

② Is a plated metal similar to a mixture of compound? Explain your answer with evidences from the experiments.

③ Is a alloy similar to a mixture of compound? Explain your answer with evidences from the experiments.

Activity 4. How can metals be prevented from corrosion?

Topics of Inquiry:

- What are the causes of iron's corrosion?
- What can we do to prevent iron's corrosion?

We have learned how metals react with other matter. Today we are going to learn how to control those reactions. The process of metal' lost of electrons are called oxidation. Especially, undesirable oxidations are referred to as corrosion. If we want to keep metals' desirable properties for the good uses, we need to make an effort to keep metals from corrosion. Today, we will examine diverse ways of preventing metals from corrosion.

1. Establishment of hypothesis: answer the following questions before the experiments.

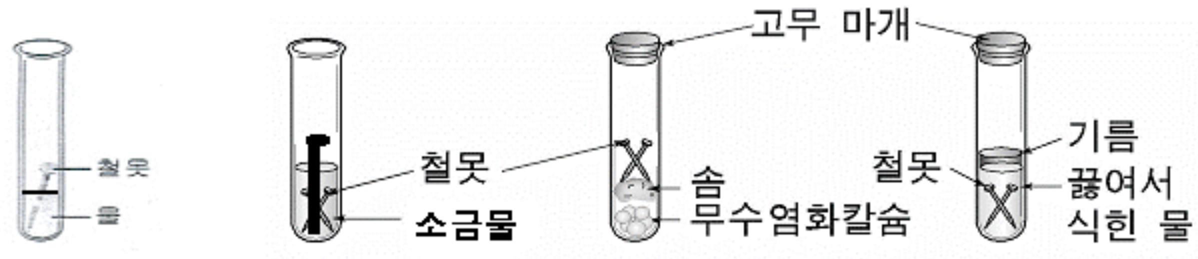
① Why do the iron bridges or gates get rusted over time?

② Many people paint the bridges or gates to prevent them from rusting. Why?

③ Tin is iron plated with zinc. Tin is used for roofs because it is resistant to corrosion from air pollution. How is it possible?

2. Procedure and Results: Follow the directions and record what you observe.
Metals' corrosion is such a slow chemical reaction that you will set up the tools and a week later watch the results.

① Prepare 4 test tubes and make a setting like the following picture.



② analyze the setting and explain the conditions for corrosion of each test tube.

③ A week later, observe the iron nails and measure the amounts of rusts. Explain the difference among the amounts of rusts.

3. Drawing Conclusions

① What causes iron’s rusting? What kind of reaction is the iron’s rusting?

② Many people paint iron bridges or gates to prevent them from rusting. Why?

③ Tin is iron plated with zinc. Tin is used for roofs because it is resistant to corrosion from air pollution. How is it possible?

Appendix C

The Six questions on the summative test

Item 1. Choose the best definition of metal from a chemist's point of view.
① All conductors of electricity
② All hard solids at the room temperature (25℃)
③ All elements placed at the left-top in the periodic table
④ All elements, except hydrogen, that are easy to become anions by acquiring electrons from other elements
⑤ All elements, except hydrogen, that are easy to become cations by losing their own Electrons

Analysis of students' concept of metal on the summative test

Choice Number	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
# of students	2	0	2	10	143
% of student	1.27	0.00	1.27	6.37	91.08
% of Correct answer	91.08				

Item 2. Choose the wrong description of the chemical properties of metal.
① Metal is likely to be oxidized by losing electrons.
② Alkali metal has the greatest reactivity among metals.
③ Metal's corrosion happens because it is easy to oxidize them.
④ Metal sometime becomes anions by acquiring electrons from other elements.
⑤ By combing with other metal, metal forms alloys which have different properties from original metal.

Analysis of students' concept of metal's chemical properties in the summative test

Choice Number	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
# of students	7	11	2	135	2
% of student	4.46	7.01	1.27	85.99	1.27

% of Correct answer	85.99

Item 3. Choose the wrong explanation of the properties of alkali metals.
① They have free electrons because they conduct electricity.
② They have weak metallic bond because they are soft, low-density metals.
③ When cut, its color of the cutting plane changes from silver-metallic to white because it is reduced by oxygen in the air.
④ Alkali metals vigorously react with water, producing hydrogen gas and basic solutions.
⑤ Their reactivity become increasingly violent as one moves down the group.

Analysis of students' concept about alkali metal's chemical properties

Choice Number	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
# of students	2	16	131	3	5
% of student	1.27	10.19	83.44	1.91	3.18
% of Correct answer	83.44				

Item 4. Decide the order of reactivity of metals using the following data.

cations / metals	A^+	B^+	C^+	D^+
A	-	×	×	O
B	O	-	×	O
C	O	O	-	O
D	×	×	×	-

The percent of correct answer was 94.90 %.

Item 5. Choose the wrong explanation of the properties of alloys and plated metals.
① Korean coins have different color form pure copper because they are alloy of copper with other metals.

② When copper is plated with zinc, it turns silver-white, while the alloy of copper and zinc has gold color.
③ Plated copper by zinc is susceptible to corrosion by diluted HCl, while its alloy is resistant to corrosion by diluted HCl.
④ Both plated copper and its alloy keep their original properties unchanged.
⑤ Both alloying and plating are used to prevent metals from corrosion.

Students' concept about alloy and plating

Choice Number	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
# of students	1	5	14	137	0
% of student	0.64	3.18	8.92	87.26	0.00
% of Correct answer	87.26				

Item 6. Choose the wrong explanation of metals' corrosion.
① Corrosion is a process in which metals gain electrons, undergo reduction, and become anions.
② Main cause of metals' corrosion is the oxygen in the air.
③ When metals are in contact with water, the corrosion process is facilitated.
④ Sea water makes ships' corrosion faster due to the salt in it.
⑤ Gas pipe made of iron can be protected from corrosion by connecting it to zinc because zinc acts as a sacrificial anode in the oxidation process.

Students' concept about metal's corrosion

Choice Number	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
# of students	148	2	3	3	2
% of student	94.27	1.27	1.91	1.91	1.27
% of Correct answer	94.27				

Appendix D

Coded students' responses and distribution in each test

Pretest		Formative test 1		Formative test 2		Posttest	
Coded Response	# of students	Coded Response	# of students	Coded Response	# of Students	Coded Response	# of Students
ABC	34	10	19	1	42	1	19
AB	32	AB	12	4	23	AD	12
AD	9	1	11	3	14	ABC	10
A	8	A	10	3,9	14	2	7
2	7	A10	9	1,4	7	A	6
1	5	8,10	9	1,9	6	AC	5
4	5	ACD	8	B3,4	4	AB	4
ACEG	4	AB3	8	BC4	4	AD1	4
DI	3	AB10	8	ABC4	4	ABC2	3
ABD	3	A1,10	6	A1,4	3	3	3
E	3	AB3,5	6	4,9	3	AC4	3
A3,4	2	8	5	9	2	E1	3
ABCD	2	3	5	A4	2	ACE1	3
ABC2	2	3,9	4	ABD4	2	AE	3
AC	2	A3,10	4	C4	2	CE1	3
H	2	AC	4	3,4,9	1	4	2
I	2	ABCDF2,5	3	1,9	1	7	2
3	1	ABC3,5	3	1,3,4	1	1, 5	2
AC4	1	AB1,10	3	A1,4,9	1	ACD2	2
E1	1	A1	2	A4,5	1	ABC3	2
1,2	1	A3	2	AC3	1	AB4	2
A1	1	A8	2	AB4	1	C1	2
AD3	1	A8,10	2	C4,9,10	1	F	2
ACD6	1	AB5,10	1	ABC	1	F1	2
ABC1,2	1	BD8	1	AB3	1	5	1
ABC3,4	1	blank	8	AB3,4	1	1,2	1
ACE	1	Yellow cells have at least one of concept 5, 8, 9 or 10, which were closely related with Activity 1.		BCF3,4,9	1	1,6	1
AB3	1			1,3,9	1	1,8	1
ABG3	1			1,4,10	1	2,3	1
ABE	1			3,4	1	2,4	1
AEG	1			blank	11	3,5	1
AE1	1			Blue cells have at least one of concept 4 or 9, which were closely related with Activity 2.		3,9	1
BC3,4	1					A1	1
BCEG	1					A2	1
EG	1					A3	1
E1	1					A4	1
blank	16					A6	1
						AB3,4	1
						ABC2,4	1
						ABC3,4	1
						ABCDE2	1
						ABE	1
						ABF	1
						ABG	1
						AC3	1
						AE4	1
						AF	1
						AF1	1
						AG3	1
						B	1
						BD	1
						BC2	1
						BC3	1
						BCF3	1
						BCF2,3	1
						BF	1
						C	1
						C4	1
						C4,8	1
						D	1
						D3	1
						DF3	1
						E	1
						F2,3	1
						F3	1
						G	1
						blank	9

			Yellow cells have at least one of concept 4, 5, 8, 9, or 10, which are closely related with activity 1 and 2.

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