Interaction between Changes of Higher-Order Thinking Skills and Changes of Academic Interest and Self-efficacy in Problem-Based Learning

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Abstract
This study examined whether problem-based learning (PBL) contributes to development of students' higher-order thinking (HOT), and the development depends on levels of students' motivation (i.e., interest and self-efficacy). Using 89 college students enrolled in Educational Psychology classes from South Korea, we conducted a t-test and repeated measure analysis to see their changes in HOT, interest, and self-efficacy and the interaction between the variables. We found students' HOT scores increased significantly after PBL than before. Further, a repeated measure ANOVA showed students belonged to HOT or lower-order thinking (LOT) groups at both the times increased their level of motivation steadily. However, the level of motivation of the students who belonged to HOT at the beginning but LOT at the end increased much more than the other three groups. On the other hand, the level of motivation of the students who belonged to the group which changed from HOT before PBL to LOT after PBL decreased after PBL. This suggests that use of PBL class should be carefully considered according to the students' HOT types and motivational changes.

Keywords: Interest; self-efficacy; Problem-Based Learning; Higher-Order Thinking

Introduction

The way how students think becomes complicated by the gap between the teacher who judges it and the students. It is necessary to judge the thinking activity first when dividing the thinking of students into Higher-Order Thinking (HOT) or Lower-Order Thinking (LOT), and usually the judgment is made from teachers' viewpoints. In fact, Bloom (1956), Resnick (1987) and others who led the discussions about the existing higher-order thinking skills divided the thinking activity of students on the basis of their teaching experiences. However, according to Schrag (1989), it is not enough to judge higher-order thinking only in the viewpoint of teachers for objective understanding of higher-order thinking skills. It is necessary to consider how and why students think in a way of HOT or LOT from the viewpoint of students based on the activity and report of students.

Schrag (1989) argued that it is required to know the circumstances and materials given to students before dividing the levels of the thinking skills of students. This argument began from a criticism of the existing scholars including Bloom and his colleagues who simply focused on dividing the levels of thinking skills of students. Even if the thinking skills of students are judged relatively objectively from the viewpoints of both the students and the teachers, a thinking activity may seem like HOT or LOT skills depending on the environment of the students who use HOT skills. One should be able to answer such questions if he/she is to obtain the fundamental ideas of students' actual usage of HOT skills that: what kinds of materials are students reading? What are they being taught?

Active learning including problem-based learning (PBL) has become a popular teaching method at universities expecting that the PBL would improve the academic achievement and develop interdisciplinary thinking of college students (Stentoft, 2017). The PBL appeals to modern university students because students have been expected to able to perform more critical and self-directed thinking through the active learning method (i.e., PBL). Indeed, it has been found that development of HOT accompanied use of PBL (e.g., Barrows, 1996). However, the co-occurrence of HOT and PBL in the field does not seem to warrant their positive relationship according to the previous studies. On one side, scholars insist PBL encourages college students' higher-order thinking skills. Scholars in this group have paid attention to scientific thinking processes such as questioning and inquiry (Alexander et al., 2011; Lewis & Smith, 1993) which appears during PBL. Thus, PBL was viewed as a good way of developing HOT. On the other side, researchers argued there is something more to consider for appropriate development of HOT rather than simply providing problems to classes. Based on an in-depth observation of students in scientific inquiry classes, Marshall and Horton (2011) found that the level of students' intellectual ability (or higher thinking skills) was negatively associated with the time spent exploring problems. College students with less developed intellectual skills spent more time exploring than managing or solving problems. The researchers concluded that instructors should provide suitable steps for each student depending on their cognitive levels rather than simply providing them with problem-based instructions.

The current study considered the discrepancy of the arguments on relationship between PBL and HOT and the early concerns of Schrag (1989), that is, the assertion that the problems of the existing education raised by Bloom, etc. cannot be solved by simple division of HOT and LOT skills. Therefore, we sought to explore predictors potentially influence to development of HOT such as PBL.

In addition to consideration of PBL as a potential contributor to development of HOT, we sought to find students' psychological assets determining development of their HOT. Considering both the psychological and physical determinants is necessary to see how HOT develop from the viewpoint of students rather than that of teachers. In this study, PBL was meant to be the physical environment, and self-efficacy (SE) and interest (INT) were referred to the students' psychological environment. The physical and mental learning environment of students was expected to ultimately make the difference in their level of thinking skills.

In this regard, the hypotheses of this study are set up as follows.

1. If college students take PBL classes (physical learning environment), they will tend to use thinking skills more in general (improvement in higher-order thinking skills).

2. After taking PBL classes, the degree of changes of academic interest and self-efficacy of college students (mental environment) will differ by the degree of use of thinking skills (occurrence of interaction between changes of level of motivation and changes of level of thinking skills).

Literature Review

Higher-Order Thinking Skills

Higher-order thinking skills were introduced by Bloom (1956) in his taxonomy as a tool to help systematic presentation of the goal of education in the U.S. (Krathwohl, 2002). To date, the term HOT has been often used as a term opposed to low-order thinking (LOT). However, when Bloom suggested the taxonomy, it meant cognitive skills presented on a continuum (e.g., from lower-order thinking skills to higher-order thinking). He put evaluation as highest cognitive function, which was followed by synthesis, analysis, application and comprehension, and finally knowledge as lowest level on the continuum. Lori Anderson, who was a student of Bloom, later changed Bloom's taxonomy in the 1990's. The biggest change between the old taxonomy and the new one was that the form of the cognitive skills was originally in noun but changed into verb. The continuum, then, became (higher skills of) creating, evaluating, analyzing, applying, understanding and remembering (lower skills). In addition, sub thinking skills were added to the underlying large category of thinking skills. Though some scholars (Schrag, 1989) argued against the Bloom and his colleagues' ideas regarding hierarchy of thinking skills, the existence of a certain order in using thinking skills based upon Bloom's taxonomy has been widely used in construction or understanding of educational courses to date.

The idea of hierarchy of thinking skills by Bloom's taxonomy is particularly important in the field because ones need to decide which cognitive function should be trained first and next in developing students' thinking skills. It does not mean that 'remembering' or 'understanding' in the lower ranks of the hierarchy are less important than 'evaluating' or 'creating'. Rather, activities in the lower ranks of the hierarchy that are basic learning ability need more time and long devotion. Thus, the fact that a person has HOT skills means that the person uses all the activities in the hierarchy more frequently than a person with LOT skills.

According to Krathwohl (2002) who improved Bloom's taxonomy furthermore, the six verbs in the new Bloom's taxonomy are categorized down into sub-verbs underlying the six upper-level verbs. More recently, they have introduced another new form of taxonomy, so-called Bloom's digital taxonomy (Churches, 2009). The digital taxonomy incorporated new verb forms and sub verbs reflecting changes in educational circumstances (e.g., frequent usage of the Internet). The sub verbs newly included in Bloom's digital taxonomy are the verbs such as social networking, social blogging, programming and filming.

Much empirical research evidenced that the difference between higher-order thinkers and lower-order thinkers does not occur simply by the level of thinking activity as appear in Bloom's taxonomy. According to a research which analyzed the profiles of students according to use of thinking skills (Authors, 2018), the types of thinkers among Korean college students were largely divided into a group of higher-order thinkers and a group of lower-order thinkers, but their thinking activities are not divisible in each group. The group of HOT tends to use the HOT skills such as 'evaluating' or 'creating' as well as LOT skills of 'remembering' or 'understanding' more frequently than lower-order thinkers did. That means that higher-order thinkers tended to use all of various thinking skills actively as opposed to their counterparts (Authors, 2018). As recognized by Schrag (1989), it seems hard to dichotomize LOT skills and HOT skills, but the category of thinking activities need to be understood on a continuum.

Problem-Based Learning, Higher-Order Thinking skills and academic motivation

Problem-based learning (PBL) has been conducted with the purpose to improve HOT skills. Since it had been activated in the late 1960's by Barrows, a medical school professor at McMaster University in Canada (Barrows, 1996), PBL was developed to improve students' skills to solve their real-life problems, rather than to gain knowledge by simple memorization. Such a type of learning activities are known effective for academic achievement for medical students who require hands-on experiences to solve problems such as diagnosing symptoms of patients (Schmidt, 1983; Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007). Centering on real-life problems, students do not need to learn all the knowledge necessary for diagnosis in PBL but diagnose the patients first and learn knowledge necessary for the diagnosis. That way, students can find out adequate treatments and prescriptions (Choi, 2004). That is, PBL is a form of learner-driven class in which students solve a given unstructured and complicated problem existing in real life by self-directed individual learning and cooperative learning with the help of teacher (Shin, 2003).

PBL provides the situation-based educational environment emphasized in Bloom's hierarchy of thinking skills in that PBL encourages students to think analyze, evaluate and create solutions for problems (Kong, Qin, Zhou, Mou, & Gao, 2014). PBL is a type of learning helpful to the contemporary education, which desperately needs practical field-oriented knowledge as it has exceedingly influenced by information literacy and retention, and enables flexible thinking (Yeo, 2005). PBL is a class platform frequently used in the modern college education as it improve self-regulatory ability and class satisfaction (Kang & Kim, 1998). While solving a problem, students can stimulate their metacognition and control the learning process by themselves.

PBL is also highlighted as it motivates students easily. For example, the MUSIC motivation model (empowerment, usefulness, success, situational and individual interest, and academic and personal caring) (Jones, 2009) has been use to analyze the learning process in a PBL for engineering students. The results showed that the project design activity, the group activity and the assistance of teachers experienced by the engineering students were significantly related with the five motivation factors (Jones, Epler, Mokri, Bryant, & Paretti, 2013). The participants in the study chose a project according to their personal interest or the usefulness of the project in relation to their future career. As a result, the program increased students' personal interests. The experiences of success in solving a problem are known to increase students' interests, which leads to the academic achievement of students in a virtuous cycle (Rotgans & Schmidt, 2011). According to a more recent analysis of the motivation-learning achievement in the PBL of Dutch and German college students (Geitz, Brinke, & Kirschner, 2016), self-efficacy, a sense of goal and deep learning had mutually significant relationship of each other.

However, a closer investigation is called for the expectation that PBL would improve the level of motivation and HOT skills. In addition to relation between the level of motivation and HOT, prior knowledge seems to have some contribution to the relationship (Busato, Prins, Elshout, & Hamaker, 2000). In fact, in the case of the engineering students examined by Marshall and Horton (2011), the students with little HOT skills, such as showing somewhat lower intellectual capacity at the beginning, spent much time exploring and managing skills and showed relatively lower achievement. Also, according to the guidelines for the design and operation of PBL at college level (Na & Chung, 2012), it is desirable to judge whether PBL class is suitable to the students before designing PBL and then to develop appropriate environments for each student. For example, when designing the situation of the problem, it is recommended to select a type of problems appropriate for the area of students' interest out of various problem types: explanation problem, decision-making problem, diagnosis and solution problem, situated cases, policy problem, design problem and dilemma.

In sum, PBL seems to be influenced by individual variables such as interest, self-efficacy, self-control and deep learning (Geitz et al., 2016; Gurpinar, Alimoglu, Mamakli, & Aktekin, 2010; Raiyn & Tilchin, 2015). However, little was known about difference by time in such variables. Studies barely analyzed how the changes of determinants are related with the improvement of HOT skills. In the current study, PBL is hypothesized to improve HOT skills of college students. Further, the amount of change of self-efficacy and academic interest were hypothesized to differ respectively by changes of HOT levels.

Methods

Participants

This study used a hundred students enrolled in four Educational Psychology classes in the first semester of 2017 at a university located in South Korea. Of them, eighty-two students performed both the pretest and the posttest and consisted of the final dataset. All the participants took classes conducted by the same instructor. Of the participants, 49 students (59.8%) belonged to the colleges of art, music and physical education (see Table 1); 13 students (15.9%) belonged to the colleges of humanities and social sciences; and 11 students (13.4%) belonged to the college of education. Seven students (8.5%) were majoring in science and engineering, and one student was majoring in medicine and life sciences taking 1.2% respectively. There were 36 female students (43.9%) and 46 male students (56.1%). The classes were designed to train pre-service teachers. The participants were composed of one freshman (1.2%), 72 sophomores (87.8%), two juniors (2.4%) and seven seniors (8.5%). Thus, the majority of the students were sophomores. No prerequisite subjects were required for the Educational Psychology classes, and most participants had little prior knowledge of education. No students had an experience of taking a PBL class before.

Table 1
Descriptive Statistics of The PBL Participants

Group		N (%)	Group		N (%)
Gender	Male	46 (56.1)	Age	20s	80 (97.6)
	Female	36 (43.9)		30s	2 (2.4)
School year	Freshman	1 (1.2)	College	Humanities and social sciences	20 (24.4)
	Sophomore	72 (87.8)		Science and engineering	12 (14.6)
	Junior	2 (2.4)		Art, music and physical education	49 (59.8)
	Senior	7 (8.5)		College of education	1 (1.2)

The PBL program

The Educational Psychology classes were subject to develop pre-service teachers' fundamental understanding of teaching. The PBL classes were conducted in the 12th, 13th, 14th and 15th week during the 15 weeks in total. The PBL classes regarded counseling and school-life guidance. The problem below is used in the study and regards a problematic counseling situation at schools. The problem was developed by a researcher who has consulted and operated PBL classes for several years and had expertise in PBL.

The problem used in the research

[General condition]
You are the homeroom teacher in charge of Class No. 2 in Grade 12 at a High School. In this school, homeroom teachers have a regular meeting at the beginning of each

semester to share their plans for teaching, career counseling and life guidance of the students.
You are to prepare materials that you will present in the meeting considering the characteristics of the students in your class. Please present your plan in accordance with the following directions.
[Format requirement of your presentation]
- Describe a systematic evaluation method for grasping the student characteristics and validate the method.
- Present plans for counseling and life guidance with the materials for grasping the student characteristics.
[Information of the high school students]
- 15 students hoping to enter college (including 1 special student with visual impairment)
- 7 students who are seeking jobs after graduation
- 22 students in total

Measures

The participants performed a pretest in April before the PBL classes began, and a posttest in June, immediately after the completion of the PBL classes. The questionnaires used in the pretest and the posttest follow.

Higher-Order Thinking skills scale for college students

We used the questionnaires developed by Author (2016) for the examination of the higher-order thinking skills of Korean university students (HOTUS). The questionnaire was developed based upon the survey results of Korean college students with the consultation of educational psychology experts incorporating the concepts of HOT skills that had been suggested by such educational psychologists as Bloom, Lipman and Resnick. The HOTUS was composed of 25 items under five sub-scales of creativity, analysis, argument, demonstration and consideration. The participants marked the degree of their agreement to the sentence proposed like “I review what I learned during the class to solve the task.” The internal consistency of the HOTUS was 0.74 for four items of the analysis factors; 0.76 for four questions of creativity factors; 0.79 for the five questions of argument factors; and 0.78 for the five questions of demonstration factors showing appropriate reliability. The internal consistency among the seven questions of consideration factor was 0.83 showing superior reliability.

Academic interest

Sixteen self-report question items were used to examine students’ subject interests. The questionnaire was reproduced by Yoon (2003) based on Schiefele’s (1991) interest theory. The subject interest in this measure was categorized into cognitive interest and emotional interest. The cognitive interest was subdivided into interest in subject contents, value of the subject and effort. The emotional interest was subdivided into efficacy about the subject and preference for the instructor. The students marked their degree of agreement to each question like “I want to be a teacher like this professor when I become a teacher” on a 5-point scale (1=not at all, 5=very much so). The internal consistency of interest in subject contents was 0.79, and those of value of the subject and the effort were 0.73 respectively showing appropriate reliability. The internal consistency of efficacy about subject, a sub factor of emotional interest, was 0.83, and that of preference of the instructor was 0.85 showing superior reliability.

Academic self-efficacy

We used the scale of academic self-efficacy developed by Kim and Park (2001). Self-confidence, self-control efficacy and preference for difficult tasks underlie the scale with 28 items. The participants reported their agreement of the pertinent statements for each types of efficacy on a Likert-type scale. The internal reliability of preference for difficult tasks (10 items) was 0.89, and that of self-control efficacy questions (10 items) was 0.90. The internal consistency of self-confidence (8 items) was 0.86 indicating good reliability.

Analysis

The current study aimed to examine the interaction between changes of HOT skills and changes of academic interest and self-efficacy of the participants before and after implementation of PBL classes. First, we examined levels of student HOT before and after PBL, and the interaction of INT and SE with the HOT difference between the two measurements time points. We particularly paid attention to the students whose pre-post HOT value changed positively (i.e., hanged from the LOT group to the HOT group) with regard to their motivation changes (pretest-posttest difference of interest and self-efficacy). Several analysis phases were incorporated for the purpose.

First, the average change of students' overall HOT before and after the PBL program were analyzed using t-test. With a significant overall difference for change (i.e., difference between pretest and posttest), the students were grouped to the HOT group and the LOT group at each time point (pretest and posttest) according to the latent profile analysis of their HOT. This initial grouping was further divided into four groups along with the time points: 1) consistent HOT group (those grouped in HOT both before and after PBL), 2) consistent LOT group (those grouped in LOT both before and after PBL), 3) LOT -> HOT group (those grouped in LOT at pretest but in HOT at posttest) and 4) HOT -> LOT group (those grouped in HOT at pretest but in LOT at posttest).

Second, the repeated measure ANOVA was conducted to examine whether the grouping (consistent HOT, consistent LOT, LOT -> HOT, HOT -> LOT) was related with degrees of changes in the students' interest (INT) and self-efficacy(SE).

Results

Descriptive statistics and latent profile analysis

Descriptive statistics of pre-post test scores for HOT, INT and SE are as follows. According to the results of a paired t-test, the mean scores of all three variables at the end were significantly higher than those at the beginning (see Table 2).

Table 2
Descriptive Statistics of Pre-Post Test For HOT, INT and SE

Source	Pretest	Posttest	*t*	*p*
HOT	3.7±0.4	3.9±0.5	-4.672**	.00
INT	3.7±0.4	3.9±0.5	-4.914**	.00
SE	3.2±0.4	3.4±0.4	-4.263**	.00

Note. Values are presented as Mean±SD; HOT=Higher-Order-Thinking; INT=interest; SE=self-efficacy.

The latent profile analysis for grouping the changes of students' HOT skills showed that two latent groups are present both before and after PBL. Table 3 shows the model with two latent profile groups are appropriate for this data.

Table 3
Model-Data Fit Indices for the Latent Profile Analysis of HOT

	AIC	BIC	SABIC	Entropy	LMRLRT	BLRT
Pre HOT(2)	4322.092	4505.002	4265.302	0.927	0.0680	0.0000
Post HOT(2)	4549.083	4731.993	4492.293	0.972	0.1841	0.0000

Note. HOT=Higher-Order-Thinking

Based on the above grouping, 29 students (35.4%) belonged to the consistent HOT group; 24 students (29.3%) to the consistent LOT group; 27 students (32.9%) to the LOT -> HOT group; and 2 students (2.4%) to the HOT -> LOT group.

Repeated Measure ANOVA for INT

A repeated measure ANOVA displayed whether changes of INT depend on the change of HOT skills (Table 4). The results captured significant interaction effect between INT and the HOT changing groups. In other words, INT significantly changed as HOT group changes (F=4.360, p=0.007).

Table 4
Repeated Measure ANOVA for INT

Source	Sum Square	*df*	Mean Square	F	p
INT(pre-post)	.101	1	.101	1.246	.268
INT*HOT change	1.060	3	.353	4.360	.007
Error	6.324	78	.081		

Regarding INT change in each group, the consistent HOT group answered 3.91(SD=0.38) out of 5 on average before PBL class, which meant slightly lower level of interest than the medium value (3). However, it was 4.12(SD=0.52) on average after PBL class, which meant slightly higher level of interest. The consistent LOT group scored 3.34(SD=0.37) on average before PBL class and 3.44(SD=0.35) on average after PBL class without much difference. In fact, Figure 1 shows that INT of the consistent HOT group and that of the consistent LOT group slightly rose. On the other hand, the average INT in the LOT -> HOT group at the posttest (M=4.05, SD=0.44) was increased significantly from the pretest (M=3.63, SD=0.37). Such a difference is apparent in the graph. The slope of the LOT -> HOT group is higher than that of the consistent HOT group and the consistent LOT group. Interestingly, INT of the HOT -> LOT group fell considerably over time. The HOT -> LOT group answered 3.93(SD=0.44) on average at the beginning but the average score fell into 3.56(SD=0.44) at the end of the semester. The decreasing INT score in HOT -> LOT group contrasts with the increasing scores in other groups.

Table 5

Changes of INT by Group Changes between Pretest and Posttest

Group	INT-pretest	INT-posttest
Consist. HOT (N=29)	3.91±0.38	4.12±0.52
Consist. LOT (N=24)	3.34±0.37	3.44±0.35
LOT -> HOT (N=27)	3.63±0.37	4.05±0.44
HOT -> LOT (N=2)	3.94±0.44	3.56±0.44
Total (N=8)	3.65±0.43	3.88±0.53

Note. Values are presented as Mean±SD

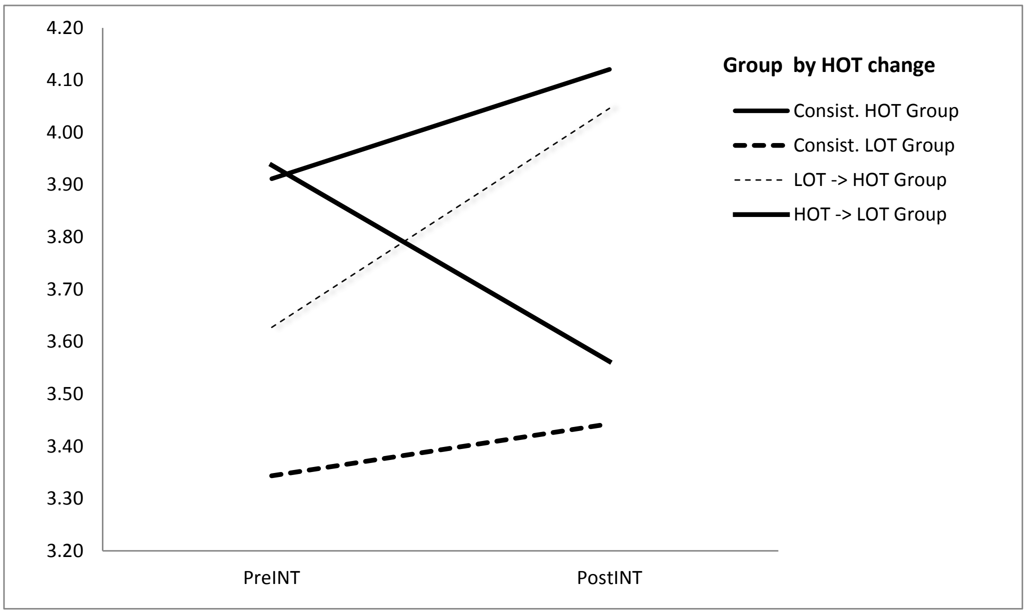

Figure 1. Changes of INT by group changes between pretest and posttest

Repeated Measure ANOVA for SE

The following are the results of the repeated measure ANOVA conducted to examine changes of SE by the HOT change groups. The examination of the change of INT between the pretest and the posttest with the covariate of the HOT change groups showed that statistically significant SE*HOT change group effect. However, there was no significant SE *HOT change interaction effect (F=2.27, p=0.09).

Table 6

Repeated Measure ANOVA for SE

Source	Sum Square	*df*	Mean Square	F	p
SE(pre-post)	.184	1	.184	2.700	.104
SE*HOT change	.463	3	.154	2.270	.087
Error	5.307	78	.068		

SE *HOT change effect also appeared. The consistent HOT group and the consistent LOT group increased from 3.39(SD=0.39) to 3.52(SD=0.46) and from 3.04(SD=0.25) to 3.14(SD=0.24) on average showing slight growth from pretest to posttest. Interestingly, the LOT -> HOT group increased from 3.23(SD=0.33) to 3.55(SD=0.23) on average and the average score in the posttest recorded the highest among the four types of group changes. On the other hand, the HOT -> LOT group showed much lower scores after PBL than before PBL (M=3.30 and SD=0.48 before PBL; M=3.23 and SD=0.43 after PBL). Difference across groups are notable in the graph. The slope of change in the LOT -> HOT group was higher than that of the consistent HOT group and the consistent LOT group and the slope of the HOT -> LOT group was negative between the two time points.

Table 7

Changes of INT by Group Changes between Pretest and Posttest

Note. Values are presented as Mean±SD

Group	SE-pretest	SE-posttest
Consist. HOT (n=29)	3.39±0.39	3.52±0.46
Consist. LOT (n=24)	3.04±0.25	3.14±0.24
LOT -> HOT (n=27)	3.23±0.33	3.55±0.23
HOT -> LOT (n=2)	3.30±0.48	3.23±0.43
Total (n=8)	3.23±0.36	3.41±0.38

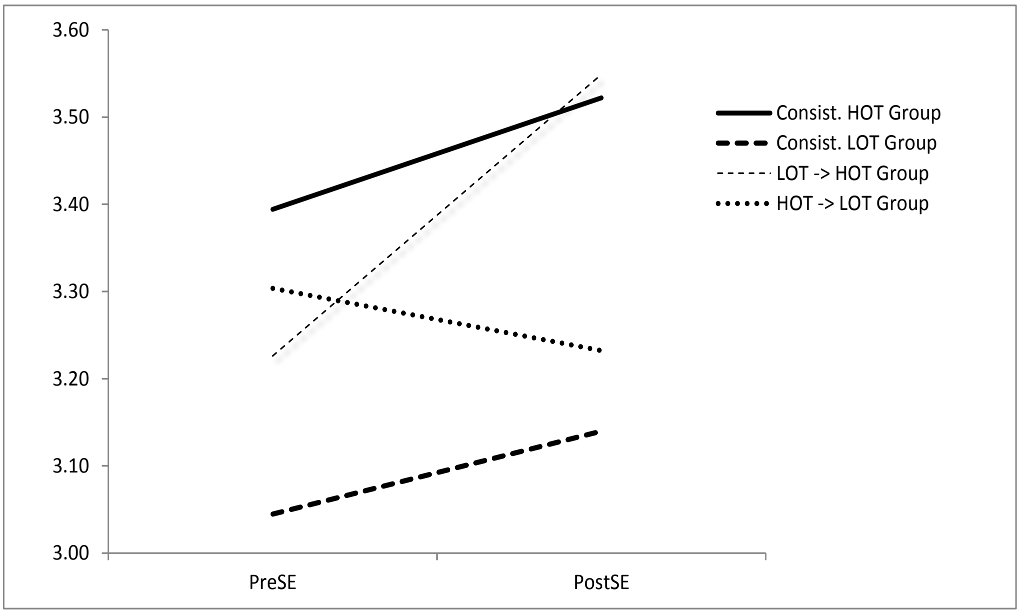

Figure 2. Changes of SE by group changes between pretest and posttest

Summary and Discussions

This study showed that PBL contributes to development of students' HOT, and the development depends on levels of students' motivation (i.e., INT and SE). Regarding the first hypothesis of this study, students' HOT scores increased significantly after PBL than before. The second hypothesis, that is, the difference in students' HOT changes by the motivation changes was supported as well. The repeated measure ANOVA showed the levels of INT or SE in the consistent HOT group or the consistent LOT group maintained before and after PBL. In other words, students belonged to HOT or LOT groups at both the times increased their level of motivation steadily.

Notable was the change of the level of motivation in the LOT-> HOT group and the HOT -> LOT group. The level of motivation of the students who belonged to HOT at the beginning but LOT at the end increased much more than the other three groups. On the other hand, the level of motivation of the students who belonged to the group which changed from HOT before PBL to LOT after PBL decreased after PBL. Such a result supports that the change of HOT level among students has some kind relationship with motivation.

As Schrag (1989) noted, ones' HOT development should be investigated with respect to conditions surrounding the ones and their characteristics (Busato et al., 2000; Yoon, 2003). This study compared the difference made by the physical circumstance variable represented by the PBL and the psychological circumstance represented by INT and SE. Those circumstances appeared to determine development of HOT skills. First, PBL contributed to developing the overall levels of HOT. Simply speaking, it seemed that PBL contributes to developing the HOT skills of students. In addition, interestingly, motivational changes represented by INT and SE had static interaction with the development of HOT. Such results are similar to the findings from the previous studies supporting the static interaction between academic achievement and the level of motivation (Lee et al., 2014; Tella, 2007). However, such a difference was not made simply by including PBL, but related with the change in students' motivation levels. The level of motivation increased remarkably in the group which had much effect of PBL, that is, the LOT-> HOT group. The SE level of the students in the LOT-> HOT group became higher than that in the consistent HOT group. It means that SE of the students increases rapidly by thinking more deeply, broadly, creatively and critically. On the contrary, the level of students' SE in the HOT -> LOT group rather decreased over time. Such a difference in the research results needs further investigation to uncover whether the level of students' HOT skills may differ by the intensity of investigation of a problem with the level of students' intellectual ability (or higher thinking skills) as proposed by Marshall & Horton (2011). The further research seems particularly necessary for the HOT -> LOT group, who are less likely to investigate problems as noted by Marshall & Horton (2011). Differently from other groups, the level of motivation in the HOT -> LOT group rather decreased after PBL.

This study showed that students' HOT skills improved after taking PBL and at the same time the level of the change of HOT skills differed by level of the students' motivational changes. This suggests that use of PBL class should be carefully considered according to the students' HOT types and motivational changes. In particular, the instructors are called for asking following question: Do the students maintain their level of motivation sufficiently? Do the students with lower INT or SE appear in the PBL class? If students show any such conditions, the students should be given enough time to investigate the problem. Teachers or instructors will become able to predict the increase or decrease of students' HOT skills by observing the changing levels of their motivation as well as their initial level of motivation. In addition, the change of motivation can be used as a clue for the decision to provide students with more time for investigation.

This study is significant in that it has elucidated the interaction between the change of the level of motivation and the change of HOT skills in PBL classes at college. However, it is necessary to make careful interpretation for the following several reasons. First, the number of the students who belonged to the HOT -> LOT group was only two, which is too few though they were paid much attention in this study. Therefore, it is difficult to conclude the results due to the small number of students in the case though the level of their motivation has decreased noticeably. It is desirable to conduct quantitative research with a greater number of students in the future. It will be also helpful to conduct qualitative examination of the reason why and how they changed so rather than simple quantification of the change in students' motivation levels. Second, application of the study result to students in various races and conditions is cautious as the result regards students only within South Korea. It is necessary to study with data from more varied and comprehensive conditions for further generalization. Third, it should be helpful to diversify research models for obtaining clearer research results. Due to the limited number of study participants, we could not make refined analysis. To overcome this limitation, we first grouped the participants according to the participants' HOT levels using latent profile analysis, and changes of the level of motivation was analyzed according to the change of their belonging to the groups. With enough cases, we might have been able to obtain more meaningful results than the current study through analyses adequate for longitudinal data, such as latent growth modeling or hierarchical analysis. Further research is necessary to compensate these limitations.

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