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Student-Centered Learning and Higher-Order Thinking Skills in Engineering Students*

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The current study aimed to investigate the use of higher-order thinking (HOT) skills by engineering students and to classify student profile groups according to the underlying constructs of HOT. We recruited 260 engineering students from six universities in South Korea. The data were analyzed in terms of the existing latent profiles and the chi-square test between the profile groups and their experience of different types of instruction. The latent profile analysis revealed that the use of HOT skills could be classified into four groups (i.e., a lower-order thinking group, a creative and argumentative group, an analytical and caring group, and a HOT group). A chi-square test between the four categorizations of HOT skill uses and instruction methods was not statistically significant. A majority of the students were classified in the HOT group. However, of the six constructs, the creativity skill was the least used, as opposed to skills that fell under other constructs. Therefore, supplementary instruction to fill this gap is suggested.

Keywords: engineering college students; higher-order thinking skills; latent profile analysis

1. Introduction

Recently, much research has been conducted on the effectiveness of various classes that aim to cultivate higher-order thinking (HOT) skills to improve the academic achievement of science and engineering students. Such student-centered classes include active learning [1], problem-based learning [2], and inquiry-based learning [3, 4]. The advantage of this student-centered approach is that students are likely to increase their level of instructional involvement and thus to solve problems as well as ultimately to develop HOT skills [5] such as application, analysis, synthesis, and evaluation, which were classified as high-level activities in Bloom's taxonomy [6].

Most scholars who have studied HOT skills have emphasized scientific thinking processes such as questioning and inquiry [7, 8]. This trend is due to the paradigm of traditional educational psychology, which interprets thought from a cognitive point of view. In recent years, however, the view that positive aspects such as "care" must be acknowledged as a subculture of thinking, especially of high thinking ability, has emerged. Lipman [9, 10], a representative scholar who makes such claims, regarded HOT skills as a combination of critical thinking, creative thinking, and caring thinking. According to this point of view, a person with HOT skills tends to consider others when examining problematic situations to find a basis for solving the problem, to synthesize various points of view and to create alternative plans [11].

However, it is difficult to conclude that inquiry-based learning and student-centered classes are related to students' use of HOT skills. Based on an in-depth observation of students in scientific inquiry classes, Marshall and Horton [12] reported that the level of students' intellectual ability (or higher thinking skills) was negatively associated with the time spent exploring problems. In other words, students with less developed intellectual skills spent more time exploring than managing or solving problems. Therefore, it is concluded that one must provide suitable steps for each student according to their cognitive levels rather than simply providing them with problem-based instructions.

Another issue in developing engineering students' HOT skills is how the underlying constructs of HOT will be manifested to students. It is unclear how these underlying constructs actually appear to students once the HOT skills are defined in consideration of the students' characteristics. Will the underlying constructs appear similar, especially among engineering students, for whom authentic problem solving is important? Or will they have a certain pattern and be divided into different groups? If several different groups of HOT skill patterns are revealed, what is the relationship between the groupings of these tendencies and the types of instruction (e.g., student-centered, instructor-centered) in which they appear? This study was conducted to answer these questions.

The current study is expected to benefit researchers and practitioners in engineering education by demonstrating ways to infer the evaluation accountability of student characteristics. For instance, these results can be used for university-level evaluation in courses at universities. The use of HOT skills by

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engineering students is also a subject of major interest for those involved in course assignment and curriculum development at the college level. Any technical university-level course that requires HOT skills can also take advantage of this study. Engineering-related studies have highlighted the importance of HOT; however, little research has been conducted to determine the relationship between HOT and the class types of engineering students. Given the importance of HOT in engineering, this study should be of interest to any engineer interested in developing an educational curriculum.

2. Methods

The latent profile analysis (LPA) and chi-square tests were conducted to determine how students in engineering majors use HOT skills and how each group relates to the type of instruction they received.

2.1 Information source

The subjects of this study were a randomly selected group of engineering college students from six universities in South Korea. The data were collected from 266 college students in engineering, and the analysis used data from 260 samples after six unreliable respondents' data were excluded. Of the respondents, 79 (30.4%) were female, 101 (38.8%) were in the first year, 30 (11.5%) were in the second year, and 72 (27.7%) were in the third year.

2.2 Higher-order thinking skills scale for university students

To measure the HOT skills of college students, we used the higher-order thinking skills scale for Korean university students (HOTUS) created by Lee [10]. The HOTUS consists of the subcategories of creative thinking, critical thinking, and thoughtful thinking. Each subcategory consists of five items related to creativity, analysis, argumentation, dialectic, and caring that explain HOT skills. Creativity is a cognitive ability to generate new and useful ideas when facing problem situations. Analysis is a cognitive ability used to contemplate a problem situation in detail. Argumentation is a cognitive ability used to provide adequate grounds for justifying conclusions about problem situations. Dialectic is a cognitive ability to provide, synthesize and devise new forms of alternatives based on various perspectives regarding problem situations. Caring is a cognitive ability to seek reasonable approaches or thoughts about problem situations based on the interest and empathy of others. The HOTUS was composed of a total of 25 items for creativity (4), analysis (4), argumentation (5), dialectic (5), and caring (7). Each subcategory score was a mean score of the relevant items based on a 5-point Likert scale (1 = very unlikely, 5 = very likely). The reliability of the HOTUS was reported as 0.879 [10].

To understand the relevance of HOT to classroom practices, the participants were asked about the teaching methods they had received in the past and divided them into three categories: professor-centered, instructor + student style, and student-centered.

2.3 Latent profile analysis

The LPA function in M plus 7.11 [13] was used to obtain the HOT profile of the participating college students. The LPA is a person-oriented approach that distinguishes groups through personal characteristics and attributes [14]. For the final model selection, the model was evaluated based on classification quality, information index, and model comparison test. First, the quality of the classification was confirmed through the entropy value, and the estimation equation was as follows [15]:

$$E_k = 1 - \frac{\Sigma_i \Sigma_k - P_{ik} ln P_{ik}}{N ln(k)} \quad (1)$$

where P_{ik} is the posterior probability of a person who belongs to group k, N is the sample size, and K is the number of latent classes. E_k is between 0 and 1, and the probability of belonging to one latent class is close to 1; as the probability of belonging to another latent class becomes closer to 0, the P_{ik} value increases. A value of approximately 0.8 or more is considered a good classification value [16].

The Akaike information criterion (AIC) [17], Bayesian information criterion (BIC) [18] and sample-size adjusted BIC (SABIC) [19] were used as information indices. For the model comparison test, the Lo-Mendell-Rubin adjusted likelihood ratio test (LMRLRT) [20] and parametric bootstrapped likelihood ratio test (BLRT) [21] were used.

A chi-square test was conducted to determine the relationship between the latent profiles and the instruction method that the students received in the past. This process was performed by checking the independency between two variables through SPSS version 22.0 [22].

3. Results

3.1 Latent profile analysis

Table 1 summarizes the descriptive statistics of the subvariables of HOT skills employed in the LPA. As seen in the table, the five subvariables of HOT skills showed a statistically significant correlation of an approximately medium level, but between some matching pairs, such as analysis and creativity and

Table 1. Correlations among Subvariables of Higher-Order Thinking Skills

	1	2	3	4	5
1. Analysis	1				
2. Creativity	0.42**	1			
3. Argument	0.22**	0.11	1		
4. Dialectic	0.53**	0.38**	0.26**	1	
5. Caring	0.46**	0.38**	0.26**	0.48**	1
Mean	3.70	3.69	2.93	3.50	3.37
S.D.	0.66	0.58	0.674	0.61	0.588

Notes. *p < 0.05, **p < 0.01.

Table 2. Model Fit in Latent Profile Analysis

	AIC	BIC	SABIC	Entropy	LMRLRT	BLRT
2 Profile	14942.9	15213.6	14972.6	0.903	0	0
3 Profiles	14759.0	15122.2	14798.8	0.895	0.4403	0
4 Profiles	14599.8	15055.6	14649.8	0.903	0.2794	0
5 Profiles	14497.6	15045.9	14557.7	0.924	0.4344	0

Table 3. Dependency test LPA × Instruction method

Instruction	Instructor-centered	Instructor + students	Student-centered	Total
Group				
1. Lower-order thinking	12 (92.3%)	1 (7.7%)	0 (0%)	13
2. Analytical and caring	58 (86.6%)	4 (6.0%)	5 (7.5%)	67
3. Higher-order thinking	96 (87.3%)	6 (5.5%)	8 (7.3%)	110
4. Creative and argumentative	57 (81.4%)	9 (12.9%)	4 (5.7%)	70
Total	223 (85.8%)	20 (7.7%)	17 (6.5%)	260

Note. The percentage represents students in each latent profile group out of the students in each instruction method.

caring and creativity, the correlation was very low or hardly existent.

Table 2 shows the results of the LPA the HOT skills of engineering students. In the LPA, the number of profiles exposed by the data is determined based on the ease of interpretation and the fit of the model. The fit of the model was checked by increasing the number of profiles from two to five.

The comparison results of model fits are well differentiated when the entropy index is 0.8 or higher [13]. The classification was almost accurate, with the entropy values of the models compared in this study all showing an entropy index of 0.8 or more. The AIC, BIC, and SABIC values all decreased as the number of latent profiles increased. The LMRLRT was significant for up to four models, and the BLRT was significant for all models, so it is difficult to determine which model is the best fit for these criteria. A researcher's judgment becomes important when multiple indices show different results [23], and in such cases, it is necessary to comprehensively consider various fit indices and theoretical interpretability. A four-group classification was employed in this study, comprehensively taking into account the ease of interpretation, fit index and other aspects.

Figure 1 outlines the four latent profiles (Groups 1 through 4) produced as above mentioned. Those groups can be named as followings based on their characteristics: Group 1 is "lower-order thinking group", Group 2 is "analytical and caring group", Group 3 is "HOT group", Group 4 is "creative and argumentative group".

The characteristics of each type of profile are as follows: First, Group 1 showed low scores in most indicators, including analysis, argumentation, dialectic and caring, compared with other groups. This group can be termed a 'lower-order thinking group.' Thirteen students belonged to this group, accounting for 5% of all the students. Group 2 had high scores in analysis, argumentation and caring and relatively low scores in creativity and dialectic. Given the high construct correlation between creativity and argumentation among the lower HOTUS scores, this group can be understood as having weak creative and divergent thinking but exceptionally strong analytical and caring abilities. Therefore, it can be called an 'analytical and caring group.' Group 2 had 67 students, comprising 26% of the total number of students. Group 3, the so-called 'HOT group' whose scores were high across all subconstructs, contained 110 students, accounting

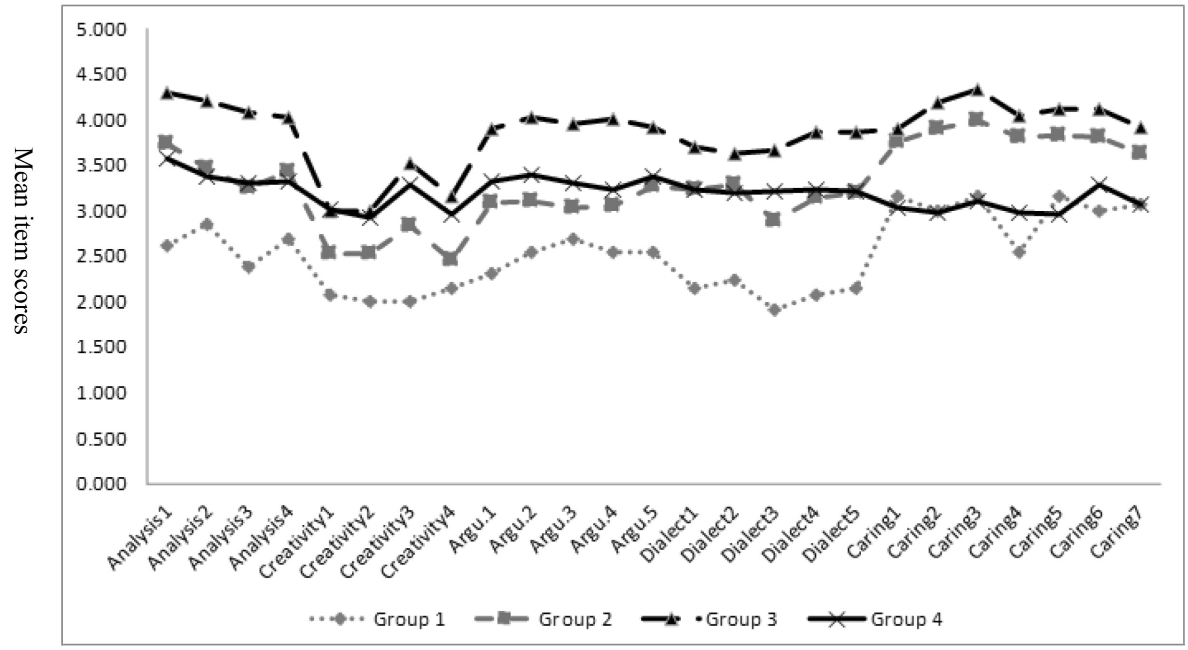

Fig. 1. Means of item scores per Latent Profile of Higher-Order-Thinking skills in engineering students.

for 42% of the total number of students. Group 4 earned relatively high scores, ranking second in creativity, argumentation and dialectic among all groups, but its caring score was relatively low. This group, which can be called a 'creative and argumentative group,' contained 70 students, or 27% of the total number of students.

3.2 Independency between the LPA and the instruction method

A chi-square independency test was conducted to see whether the LPA classification is related to the group members' experience of instruction methods. The results indicated no statistical significance (χ^2 = 4.775, DF = 6, p = 0.576). Therefore, one cannot reject the hypothesis that the latent profile group is independent of the instruction method. In other words, the two variables can be said to be dependent on each other. The student numbers for each group are presented in Table 3. The independency between the two variables appeared, and the main effect for each variable should be meaningful. Most of the engineering students who participated in this study (N = 223, 85.3%) received instructor-centered classes. Of the classified groups, Group 1 (a lower-order thinking group) was prone to experience an instructor-centered approach. All the students in Group 1 except one reported that they had received instructor-centered classes. The likelihood of receiving instructor-centered classes decreased from Group 1 to Group 3, Group 2, and Group 4. Interestingly, an analytic and caring group (Group 2) reported a greater likelihood of experiencing a student-centered approach than other groups. However, the changing trends of student-centered approach across groups were not statistically significant, which meant it was difficult to distinguish group differences based on the student-centered instruction method.

4. Discussions

The purpose of this study was to investigate how engineering school students use HOT skills and how their current use of HOT skills is related to the types of teaching they have received in the past.

The engineering school students showed four groups with HOT skills: a considerable number of participants were classified as the "HOT group" (Group 2), which frequently uses all of the HOT skills. In addition, a "creative and argumentative group" (Group 4), an "analytical and caring group" (Group 3), and a "lower-order thinking group" (Group 1) frequently appeared among the engineering students. However, most students, including those classified in the "HOT group," used relatively less of the creativity skill.

Most of the engineering students who participated in this study reported that they had received instructor-centered classes. A very small number of students had received student-centered classes, and many of them were in the analytical and caring group (Group 2) or the HOT group (Group 3). This may reflects the recent concerns of engineering educators to highlight development of students' sustainable thinking. However, the type of instruction experienced did not show a significant relationship with the HOT group category.

The relevance of the use of HOT skills and the types of classroom instruction that the engineering students had received was not significantly prominent in this study. On one hand, the reason for this deviation may be related to the fact that many of the participating students were classified in the HOT group that used advanced thinking skills.

These results are somewhat encouraging; however, it is necessary to provide courses that emphasize creative thinking skills, considering that most engineering students in the current study used less creative thinking skills than other HOT skills. Indeed, previous research has pointed out lack of student-centered instruction [24] despite much of the engineering education curricula requires the pedagogical paradigm-shift [25]. On the other hand, it is possible that simply enforcing student-centered instruction may not necessarily be helpful in promoting HOT skills for engineering students. This tendency has already been noted in the work of Marshall and Horton [12]. Theoretical studies to further confirm this tendency should be conducted in the future.

5. Conclusions

The engineering students' thinking styles have four latent profiles such as "lower-order", "analytical and caring", "higher-order", and "creative and argumentative" according to our Latent Profiles Analysis. Of these four types, "lower-order thinkers" appeared to have more experiences of instructor-centered classes than other three profiles. In conclusion, engineering students require more of the student-centered classes than instructor-centered classes for further higher-order thinking skills including analytical and caring skills. However, our statistical analysis did not verify the group differences at their significance levels, which needs further investigation.

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