International Journal of Engineering Education Vol. 36, No. 1(B), pp. 483–490, 2020
Printed in Great Britain

0949-149X/91 $3.00+0.00
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Development of a Teamwork Skill Scale for Engineering Students*

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Engineers have to work with many people, each with various level of knowledge, as a team because most work in the engineering field involves complex projects. To teach teamwork skills properly in engineering schools, the teamwork skill levels of students should be assessed. Many professors have measured teamwork skills in their classes, yet they still have questions as to how they can teach and measure teamwork skills. This study aims to identify teamwork skills and their subordinate areas necessary for engineering students as well as to develop the appropriate scales to measure such skills. To achieve such goals, a literature review and survey were conducted. Teamwork skills and their subordinate areas were reviewed. A survey was administered to 343 students of three engineering schools in the Republic of Korea and a factor analysis was conducted. The scale was completed with five factors, each of the common and individual skills. Reliability, collaboration, a sense of responsibility, listening courteously, and adaptability were selected as the common skills; and for the individual skills, the roles of leader, innovative executor, coordinator, terminator, and judge were suggested. The abilities needed for each role were defined as leadership, problem-solving ability, interpersonal relationship ability, communication ability, and decision-making ability. The components of the teamwork skills that were developed in this study can be used to measure teamwork skills and as preliminary data for the development of education programs needed to concretely improve the teamwork skills of students.

Keywords: teamwork skills; teamwork skill scale; common skills; individual skills; engineering education

1. Introduction

With the fluctuating business environment that firms face, new corporate structures that can flexibly adapt to a new environment rather than traditional hierarchical structures are required nowadays. Many transform their corporate structures to team-based units because of this realization. Team structures are not merely a collection of members; they should function to facilitate the smooth utilization of resources. Teamwork is essential to this function.

Under these social circumstances, the development of teamwork skills has become a vital area in engineering education. The development of teamwork skills is also essential for university students as a fundamental work skill as well as cooperative work skills and interpersonal relationship skills [1, 2]. In particular, engineers have to work with many people, each with various levels of knowledge, as a team because most work in the engineering field involves complex projects. Thus, the importance of teamwork skills becomes more emphasized in engineering school education. This is because the value that engineering students obtain from teamwork could overcome limitations in knowledge and time posed by working alone. A broad understanding of the matters and synergy available from analysis of the engineering problems in various aspects are known to be generated more spontaneously when engineers and technicians work together as a team [3].

In engineering education, a team can be defined as an interdependent small group of members who have interaction skills with which to acquire complementary technological knowledge and attitudes and to produce comprehensive results [4], or as a group of members who have various skills in diverse engineering fields with which to achieve a common purpose [5]. In addition, teamwork in engineering education can be defined as an activity in which engineering school students from various backgrounds interact and cooperate to accomplish a team project, and teamwork skill can be defined as the ability required to effectively demonstrate teamwork [6]. However, many researchers still focus more on the concept of teamwork in the workplace than in the university, which shows that there are limits to the accurate integration of the concept of teamwork in business into the educational environment [7].

Nevertheless, teamwork skills are recognized a very important for engineering students. The Accreditation Board for Engineering and Technology (ABET) designated it as one of 11 program outcomes. The Accreditation Board of Engineering Education of Korea (ABEEK) also designated it as one of its 10 program outcomes, suggesting that it is

* Accepted 19 November 2019.

an essential ability and natural disposition for students to be equipped with through education. This means teamwork skills should be taught to students in engineering schools, evaluated levels of achievement for accreditation of engineering education, and served as a feedback mechanism for subsequent students.

Joo et al. reported that 'communication and cooperation skills' are the most essential capacities for engineering workers based on their survey on the work abilities of people who had completed the accredited engineering education courses, subject to the graduates and industries [8]. These are essential skills for one to efficiently process tasks and reduce conflicts at work in either departments or teams. From the survey results, it is possible to know that these are the abilities most demanded of students but which are, as yet, not properly emphasized in engineering schools.

To teach teamwork skills properly in engineering schools, the teamwork skill levels of students should be assessed. However, it is also important to allow students to experience many projects based on team activities. In particular, what is most troubling in team activities is the problem of the 'free ride'; and as such, exit interviews and peer review tools are used in many universities to measure teamwork skills. A proper assessment focuses on the process, not the result, because teamwork, problem-solving, design and an ethical understanding of all the achievements in engineering education are accompanied by the learning of various processes. Thus, student performance should be observed, but this is just an ideal step because it costs too much. Therefore, most studies use self-review and peer review at the same time [7, 9–11].

However, when a researcher uses the peer review method, it is often found that students usually give almost perfect scores to their team members instead of giving a differentiated evaluation. Also when exit interviews are promoted, the engineering school professors perform the interviews without sufficient knowledge of teamwork skills, so the evaluation results are not appropriate or accurate.

To solve this assessment problem of teamwork skill, researchers have done a lot of researches, that is, developing an assessment method to focus on completing each individual's contribution or process instead of focusing only on the contribution of the final outcome performed by the group [12] or using learning analytics to improve teamwork assessment, factors based on interaction among learning agents were proposed [13].

Many exiting studies have contributed to a better assessment of teamwork, but there is no way to give an assessment when team members are given a role in team activities and perform well on an individual. To improve this, it is necessary to analyze objectively and to extract the subordinate components of teamwork skills suggesting which subcomponents are appropriate for each team member's role.

If engineering school professors and students recognize the subordinate components of teamwork by role with team as well as the concept of team and teamwork, the learners' motivation to achieve their tasks can be strengthened and their satisfaction could be improved [14].

Therefore, this study aims to identify teamwork skills and their subordinate areas necessary for engineering students to solve conflicting problems in the field of engineering education regarding measurement of teamwork skills as well as to develop the scales to measure such skills.

This paper is structured as follows: Section 2 presents the result of literature review. Section 3 describes the methodology that has been applied for development of teamwork skill scale. Section 4 shows the explorative factor analysis result and teamwork skill scale construction. Finally, in Section 5 the results of this study are discussed and suggested some proposals for the further research.

2. Literature Review

2.1 The Concept and Components of Teamwork Skill

In engineering education, a team can be defined as a group whose members possess various types of engineering knowledge and skills and perform their roles and responsibilities by interacting to achieve the common goal of the team [6]. Teamwork skill, which the members of the team should have, can be considered the ability to demonstrate teamwork effectively. Teamwork skills are used in this study where team competency was used in previous studies. With regard to the components of teamwork skills, Steven and Campion divided individual teamwork KSAs (Knowledge, Skills and Attitudes) – the teamwork knowledge, skills and attitudes that effective team members need – into two main categories: interpersonal relations (conflict resolution, cooperative problem-solving and communication) KSAs and self-management (goal-setting, performance management and task coordination) KSAs [15]. Cannon-Bowers et al. listed 130 skills and actions that team members need to effectively perform a new role and a team task, which they culled from previous studies on teamwork skills and classified into eight core actions: adaptability, shared perception of a situation, outcome tracking, outcome feedback, leadership/team management, interpersonal relationship skill, communication skill and decision-making skill [16].

In addition, Baker et al. presented a Teamwork Skill Questionnaire, which had a total of 36 ques-

tions (six questions for each of six components), by suggesting the following teamwork skills: adaptability, communication, coordination, decision-making, interpersonal skills and leadership [17]. Paris et al. suggested the elements of teamwork skill by dividing teamwork skills into those that involve the process and those that involve the result, and dividing them again into individual and team levels [18]. In other words, they divided the elements of the process into individual elements (cognition and a specific task skill) and team elements (information exchange, communication, supporting action and team leadership), and divided the elements of the result into individual elements (accuracy and potential) and team elements (goal performance, overall accuracy and potential).

As the elements of teamwork skill vary across scholars, this study used the results of the research for engineering students [19]. This study confirmed 22 elements of teamwork skills for engineering students using the Delphi technique; understanding of team's work and performance, adaptability, responsibility, consideration, mutual trust, sharing objectives, sharing information, listening courteously, feedback, data analysis, cooperation, goal setting, role distribution, decision making, motivation, persuasion, initiative, planning, time management, problem solving, writing, and complication management.

2.2 Teamwork Skill Measurement

Baker et al. sought to measure teamwork skills by focusing on the skills that an individual needs to become an effective team member [17]. The best way to measure teamwork skill is, of course, to use the current team situations wherein teamwork skill can be directly measured, but this approach is difficult. Therefore, a self-reporting questionnaire was indirectly used instead. This tool was used in various environments, and its reliability was found to be 0.84–0.97 [11].

Winter & McCalla suggested the following four factors of a successful team: functional knowledge and skill, teamwork skill and social intelligence, task type and contextual state [11]. Considering these factors, they measured the group outcome based on team communication, feedback, leadership, monitoring and orientation; and they used the types of team roles that Belbin suggested to concretely measure the various characteristics that determine individual teamwork skills [20].

Belbin said a successful team consists of people who faithfully perform nine different team roles, their performance of which determines the degree of success of the team [20]. Belbin suggested the nine types of team roles as: team workers/coordinator, implementers, specialist, plants, resource investigators, monitor evaluators, shaper, and completer/finishers. He claimed that when the roles are assigned properly and fairly and when a team member performs each of those roles, the team becomes well-balanced and effective.

Han & Bang redefined the nine team roles suggested by Belbin, using the Delphi technique, to make them more appropriate for engineering education, divided them into five roles (leader, executor, innovator, coordinator and judge), defined the teamwork skill elements that are required in all the roles as common skills and the teamwork skill elements that are required uniquely in each role as individual skills, and allowed the individual skills to overlap [6]. To be more specific, there were 11 common skills (understanding of the team task and activities, adaptability, sense of responsibility, consideration, mutual trust, sharing of the same goal, sharing of information, listening courteously, feedback, data analysis, and cooperation), and the individual skills were divided into six for a leader (goal-setting, role distribution, decision-making, motivation, persuasion, and driving force), four for an executor (planning, time management, problem-solving, and document-writing), three for an innovator (goal-setting, motivation, and problem-solving), three for a mediator (role distribution, persuasion, and conflict management), and three for a judge (goal-setting, decision-making, and planning).

In this study, to measure the teamwork skills of engineering school students, their skills were divided into common and individual skills according to their role in the team.

3. Methodology

This study aims to develop a teamwork skill scale for engineering school students. Toward this end, teamwork skills and their subordinate areas were used [6]. An agreement was reached thrice by 20 specialists, who included professors at engineering schools, doctors of pedagogy, and people in industry on the concept of teamwork skills and their subordinate components for engineering school students from a previous study, using the Delphi technique. The 22 components of teamwork skill were confirmed. Based on the identified teamwork skills and their subordinate areas, the teamwork skills of engineering school students who performed actual team activities were measured, and a teamwork skill scale was finally developed through a factor analysis of the measured results.

A questionnaire survey was administered to 343 students of three engineering schools, 270 (78.7%) of whom were male and 73 (21.3%) were female. The majority of the subjects were second-year students (199, 58.0%). Among them, 273 students (79.6%)

had performed a team project before and the average number of team projects they participated was 2.3 times.

A factor analysis was conducted through orthogonal rotation (varimax) using the principal component analysis method. Orthogonal rotation (varimax) is a method of rotating while maintaining the angle of 90 degrees between factors assuming that there is no correlation between factors. This method is used in most cases because the relationships between variables and factors that simplify the columns of the factor matrix are clear and easy to interpret. The factors were determined based on their eigen-value (> 1.0). The number of factors was restricted if the result was not produced.

4. Results

4.1 Explorative Factor Analysis Result of Teamwork Skills

In this study, a teamwork skill scale was developed by dividing team roles into five roles based on those that require common skills and those that require individual skills, according to a study of Han & Bang [6]. Orthogonal rotation (varimax) was conducted on 22 questions on common skills and 22 questions on individual skills out of a total of 44 questions (two questions each for the 22 components of teamwork skills) using the principal component analysis method. The internal consistency coefficient (Cronbach α) of all 44 questions showed a high reliability level, measuring 0.945: 0.898 for common skills and 0.916 for individual skills.

A factor analysis of the common skills was performed through orthogonal rotation (varimax) using the principal component analysis method, and the factors were set based on the eigen value (> 1.0). The detailed results are shown in Table 1. First, the sample adequacy for the 22 common skill questions was identified based on a scree test, the Kaiser-Meyer-Olkin measure of sampling adequacy, cumulative dispersion, and the content of the questions. The scree test showed a steep slope, and the Kaiser-Meyer-Olkin measure of sampling adequacy was

Table 1. Factor analysis result of common skills

Common skill	**Component**				
Sharing information1	0.755	0.275	0.169	0.023	–0.071
Sharing information2	0.701	0.232	0.130	0.032	0.067
Understanding of team's work and performance1	0.656	–0.075	0.124	0.212	0.033
Mutual trust1	0.592	0.372	0.064	0.146	0.188
Mutual trust2	0.568	0.258	0.056	0.344	0.235
Consideration1	0.563	0.026	0.224	0.137	0.131
Data analysis1	0.190	0.736	0.121	–0.018	0.017
Feedback1	–0.047	0.683	0.258	0.064	0.154
Feedback2	0.334	0.674	0.077	0.245	–0.022
Cooperation2	0.148	0.647	0.168	0.060	0.172
Data analysis2	0.212	0.565	0.390	0.114	–0.091
Cooperation1	0.417	0.477	0.325	0.139	0.071
Sharing objectives1	0.344	0.391	0.350	0.034	0.229
Responsibility2	0.239	0.208	0.731	0.043	–0.131
Responsibility1	0.256	0.294	0.643	–0.033	0.008
Sharing objectives2	0.236	–0.049	0.537	0.434	0.085
Understanding of team's work and performance2	0.071	0.212	0.507	0.046	0.182
Consideration2	–0.081	0.408	0.494	0.114	0.312
Listening courteously 2	0.114	0.073	0.066	0.856	0.003
Listening courteously 1	0.370	0.275	0.060	0.681	0.105
Adaptability2	0.100	0.058	–0.018	0.077	0.849
Adaptability1	0.356	0.225	0.364	–0.001	0.579
Eigenvalue	7.343	1.786	1.189	1.114	1.102
% of Variance	33.378	8.118	5.405	5.065	5.009
Cumulative %	33.378	41.496	46.901	51.966	56.975

Kaiser-Meyer-Olkin Measure of sampling Adequacy = 0.907. Bartlett Test of Sphericity χ^2 = 2649.824, df = 231, sig = 0.000.

good at 0.907. The cumulative dispersion of the five factors was 56.975%, and their chi-square was 2649.824 in Bartlett's test of sphericity ($p < 0.001$), which proved that the variables are linearly related, thereby disproving the hypothesis that the correlation between the variables is 0 and showing that the data are suitable for analysis.

As for the results of the factor analysis for the common skills, factors 1-3 had more than two elements, and factors 4 and 5 had a single component. In other words, factor 1 was mainly composed of information-sharing and mutual trust; factor 2, data analysis, feedback, and cooperation; factor 3, a sense of responsibility; and factors 4 and 5, a single component each: listening courteously and adaptability, respectively.

The same method was used for the factor analysis of the individual skills. The detailed results are shown in Table 2. First, the sample adequacy of the 22 individual skill questions showed a steep slope in the scree test, and the Kaiser-Meyer-Olkin measure of the sampling adequacy was good at 0.914. The cumulative dispersion of the five factors was 59.336%, and their chi-square was 2971.039 in Bartlett's test of sphericity ($p < 0.001$), which proved that the variables are linearly related, thereby disproving the hypothesis that the correlation between the variables is 0 and showing that the data are suitable for analysis.

The individual skills were also divided into five factors for each role. Factor 1 was mainly composed of planning, time management, driving force, and problem-solving; factor 2, role distribution and goal-setting; factor 3, motivation; factor 4, document writing; and factor 5, decision-making.

4.2 Teamwork Skill Scale Construction

The teamwork skill scale was formed by integrating the results of the factor analyses of the teamwork

Table 2. Factor analysis result of individual skills

Individual skill	**Component**				
	1	**2**	**3**	**4**	**5**
Plannig2	0.703	0.235	0.105	0.154	0.041
Plannig1	0.676	0.286	0.168	0.113	0.008
Time management1	0.659	0.053	0.080	0.292	0.244
Initiative2	0.635	0.060	0.240	0.165	0.244
Time management2	0.629	0.251	0.119	0.249	–0.068
Problem solving2	0.589	0.130	0.305	0.143	0.270
Problem solving1	0.567	0.271	0.292	0.111	0.118
Persuasion2	0.564	0.183	0.311	0.032	–0.185
Initiative1	0.509	0.054	0.306	0.222	0.012
Role distribution1	0.253	0.820	0.073	0.116	–0.006
Role distribution2	0.337	0.712	0.079	0.004	0.211
Goal setting1	0.104	0.644	0.268	0.365	–0.029
Goal setting2	0.081	0.544	0.430	0.404	–0.098
Motivation 2	0.251	0.151	0.783	0.093	–0.042
Motivation 1	0.248	0.141	0.716	0.082	0.165
Complication management2	0.356	0.135	0.581	0.191	0.220
Writing 1	0.307	0.128	0.096	0.798	0.050
Writing 2	0.265	0.165	0.140	0.793	–0.028
Decision making 2	0.231	0.098	0.235	0.038	0.698
Persuasion 1	0.334	0.218	0.307	0.111	–0.615
Decision making 1	0.369	0.385	0.183	–0.053	0.429
Complication management 1	0.219	0.226	0.292	0.279	0.348
Eigenvalue	8.168	1.555	1.219	1.080	1.033
% of Variance	37.126	7.066	5.541	4.909	4.694
Cumulative %	37.126	44.192	49.733	54.642	59.336

Kaiser-Meyer-Olkin Measure of sampling Adequacy = 0.914. Bartlett Test of Sphericity $\chi^2 = 2971.039$, df = 231, sig = 0.000.

skill components and of the common and individual skills depending on the role as shown in Table 3.

First, to measure the teamwork skills depending on the role, they were mainly divided into common skills and individual skills. The common skills were composed of a total of five factors, based on the factor analysis results: factor 1 was the combined information-sharing and mutual trust, and was thus named reliability, which is the ability to take part in team activities based on the other team members' trust in him or her. Factor 2, the subordinate factors of data analysis, feedback, and cooperation, was named collaboration, which is the ability to perform tasks by cooperating with the other team members. Factors 3–5, the original components of teamwork skill, were named as a sense of responsibility, listening courteously, and adaptability, respectively.

The factor analysis results were matched with the roles, as the individual skills were divided into five factors and the roles were also divided into five. Factor 1 was adjudged to be the ability that the executor should plan, manage time, solve problems, and be the team's driving force. Therefore, it could be defined as the ability to solve problems with a driving force, so the corresponding teamwork skill component was named 'problem-solving ability'. Furthermore, it was suggested that the role that requires this ability be named 'innovative executor'. Combining role distribution and goal-setting, factor 2 is the ability to set a team and project goal and give directions; and based on these, to distribute roles to suit the team members' abilities. Thus, the corresponding teamwork skill component was named 'leadership', which can be considered the leader's role. Factor 3 was named 'interpersonal relationship ability' as it is the ability to induce cooperation with other team members by motivating them to perform team activities while resolving conflicts that can happen between the team members and maintaining the spirit of teamwork. The suggested name of the role that requires this ability is 'coordinator'. Factor 4, which is the ability to enable one's team members to communicate effectively and help them finish team activities by completing document writing, was named 'communication ability', and the suggested name of the corresponding role is 'terminator'. Factor 5 is decision-making, so it was named 'decision-making ability', which is the ability to draw up a united decision from among the team members with a good grip of the team situation; and the suggested name of the role that requires this ability is 'judge'.

Except for using self-reported questionnaires as a method for evaluating teamwork skills, existing researches aiming to be more objective have developed teamwork skill testing tools based on teamwork sub-capacity elements such as communication and adaptability. Little attempt was made to objectively evaluate the teamwork skills based on role of the team. In addition, there was no tool for evaluating teamwork skills in consideration of the common skills required by all members and the individual skills required for each role based on the team activities performed in the field of engineering education.

Table 3. Teamwork Skill Scale for Engineering Students

	Teamwork skill components	**Definition**
Common Skills	Reliability	The ability to take part in team activities based on the other team members' trust in him
	Collaboration	The ability to perform tasks by cooperating with the other team members
	Responsibility	Sincerity and sense of responsibility in performing one's own role (task) in the team instead of shifting it to the other members
	Listening courteously	Willingness to listen carefully to the opinions of the other team members for smooth communication
	Adaptability	The ability to effectively adapt to the team environment as a team member
Individual Skills	Problem solving (innovative executor)	The ability to solve problems with driving force based on the team goal and roll of team members
	Leadership (Leader)	The ability to set team and project goals, to give directions, and to distribute roles to suit the team members' abilities based on these
	Interpersonal relationship (Coordinators)	The ability to promotion cooperation with other team members by motivating them to perform team activities while resolving conflicts that can occur between team members and maintaining the spirit of teamwork
	Communication (Terminator)	The ability to enable one's team members to communicate effectively and help them finish team activities by completing document writing
	Decision making (Judge)	The ability to draw up a united decision from among the team members with a good grip of the team situation

5. Conclusions

This study aims to develop a teamwork skill scale for engineering students. The 22 components of teamwork skill derived using Delphi techniques were suggested by dividing them into common and individual skills depending on five roles.

Based on this research, a survey was conducted among engineering students and factor analysis was conducted to develop a substantive teamwork skill scale. The scale was completed with five factors each of the common and individual skills. Reliability, collaboration, a sense of responsibility, listening courteously, and adaptability were selected as the common skills; and for the individual skills, the roles of leader, innovative executor, coordinator, terminator, and judge were suggested. The abilities needed for each role were defined as leadership, problem-solving ability, interpersonal relationship ability, communication ability, and decision-making ability.

The teamwork skill scale for engineering students that was developed in this study shows that each member needs to have a basic ability hinged on basic knowledge of the team, and to have skills contingent on their own roles in the team to achieve the team's goal. In other words, the components of teamwork skill that were derived from this study additionally included specific skills, depending on the tasks of the engineering students in the team. However the existing teamwork skills suggested only general abilities required for team activities.

In addition, it is believed that the teamwork skill scale can be used sufficiently by engineering students to check and develop their own teamwork ability while they are in school, because they can diagnose and understand their own teamwork ability using the scale.

Based on the results of this study on the development of a teamwork skill scale for engineering schools, the following proposals are thus made.

The components of teamwork skill that were developed in this study can be used to measure teamwork skills and as preliminary data for the development of the education programs needed to provide concrete improvements to the teamwork skills of students. It is necessary to develop and run education programs capable of improving each element of teamwork skill by diagnosing which such elements are deficient among the engineering students as one of the most essential abilities when entering industry after graduation is teamwork.

Weighting is also needed when dividing teamwork skills into common skills and individual skills. Although the five common skills and the skills needed for each role are all important, the importance of the teamwork skill that engineering students should have may differ by factor, and the skills needed for each role may vary depending on the characteristics of the team task or the team composition.

The most active interaction is achieved when the team members are five, five roles of individual skills are suggested. Therefore, if the educational environment is not allowed and the team is not composed of five members, the role suggested by this study cannot be utilized, and it is necessary to adjust the integration and present it according to the situation.

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