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The Wheel Model of STEAM Education Based on Traditional Korean Scientific Contents

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The Korean STEAM education pursues a convergent human resources education, but there are shortcomings associated with it due to the fact that it excludes the Humanities in its curriculum. This study embodies the accomplishments from the design and field application of the STEAM education model that has added Humanities fields (history, geography, and bibliography) to the five areas of STEAM (science, technology, engineering, art, and mathematics). The core principle of STEAM education is to utilize the traditional sciences as a medium that connects STEAM and the Humanities. It is designed to incorporate the eight core subjects as discipline studies of eight subjects and be implemented through the wheel model, developing into a multidisciplinary system. The STEAM education model was applied at two high schools over a two-year period as pilot programs. Both cases have undergone verification by the academia and have been reported in the news by the Korean Broadcasting System (KBS).

Keywords: discipline study, multidisciplinary study, STEAM education, traditional Korean science, wheel model

INTRODUCTION

Recently, because converged academics that span across different fields of studies have become the driving force of the creation of cutting edge knowledge, learning the detailed procedures of convergent knowledge has had great significance educationally (Jacobs & Borland, 1986; Lee, 2003). The reason why a lot of educators underscore experiences by students and emphasize project methods that expand the breadth of curriculums to everyday life, such as field learning, lab exploration, interdisciplinary activities, etc., is not unrelated to this (Dewey, 1916; Kilpatrick, 1922). In December 2009, the Korean Ministry of Education (KMOE) supplemented and improved the existing subject-centered curriculums, which had been transformed into a complex format, to foster key competencies and creative experience activities, such as voluntary activities, extracurricular activities, volunteer activities, career activities, and autonomous school curriculums, which are

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suitably helpful for an individual's career path (Korean Ministry of Education [KMOE], 2009).

In its effort to implement convergent human resources education, which is emphasized in the reformed curriculum, the KMOE has been expanding and proliferating STEAM education, which has been promoted by the Korea Foundation for the Advancement of Science and Creativity (KOFAC). KOFAC's STEAM is an acronym which stands for science, technology, engineering, art, and mathematics, and serves as a benchmark of the concept that was developed into STEAM by adding art to STEM—a move spurred by the National Science Foundation (NSF) of the United States (Yakman, 2010). The KMOE has, by restructuring the learning contents of science, technology, engineering, art, and mathematics to become key competency-oriented through STEAM education, been promoting the policy of combining inter-subject links and artistic techniques (KMOE, 2009). KOFAC systemizes theories about STEAM education and suggests its application by defining the principles of STEAM education, developing customized measures for each school or class, and searching for efficient course models. KOFAC develops STEAM-related intensive courses in science and technology for high school students with their future academic careers in sight (Korea Foundation for the Advancement of Science and Creativity [KOFAC], 2011). Hence research activities and projects are particularly emphasized.

However, in the educational environment of Korea that is not highly exposed to research activities and projects, the convergent human resources education based on the KMOE's STEAM structure has been experiencing a lot of trial and error. In the field, group activities such as school tool utilization activities using robot kits, product development in pursuit of aesthetic beauty, and exhibition events that productize scientific phenomena are often misunderstood as convergent human resources education. Such occurrences may be attributable to the fact that the circumstances in Korea, in which the STEM/STEAM education has been accepted, are different from those of the United States (Tang, 2012; Sanders et al., 2011). However, such could also be due to the lack of specific education models that can design convergent human resources education programs. In order to implement a new educational movement, the Korean STEAM education, due to its starting from a situation where there were a lack of basic research and actual studies that supported this research, is not able to present a detailed blueprint despite the fact that it is supposed to suggest an exemplary prototype (Baek et al., 2011).

Although the Korean STEAM education is pursuing a convergent human resources education by going beyond mathematics and science education, based on the fact that it has excluded Humanities subjects, it may be limited in terms of being recognized as a true Convergent Human Resources Education. In this study, STEAM expands its range of convergence to the Humanities. A STEAM-Education Model involving a teacher engaging in the activities enthusiastically is suggested.

State of the literature

- Throughout STS (Science, Technology and Society), STEM (Science, Technology, Engineering and Mathematics) & STEAM(STEM+Art), Korea has been steadily adopting overseas scientific educational movements to grow the Competence of Convergent Human Resources.
- Korea, which has a tradition of strong subject-centered curriculums, reformed its educational courses into the curriculums combining Natural Science and Humanities (Liberal Arts) in 2015.
- Although many educational researchers have been developing STEAM educational programs, there have been their limits, as a Humanities field was regarded as Art courses or excluded at all from the courses.

Contribution of this paper to the literature

- This paper provides the researchers a detailed strategy on enhancing the training of the Competence of Convergent Human Resources.
- The successful examples of these 2 schools introduced in this paper will provide well-harmonized cases of Natural Science and Humanities throughout the projects the Traditional Korean Scientific Contents utilized.
- The Wheel Model provides supports for teachers & researchers to discover and develop effective, applicable STEAM education contents.

STUDY PURPOSE

The first goal of this study is to build an educational model converging STEAM and the Humanities and to verify its potential as it is applied onto the actual education field. A convergent human resources education needs to have a wide scope that encompasses the fields of science, technology, engineering, art, and mathematics, along with the fields of the Humanities. The traditional Korean sciences include the elements of science, technology, and engineering, and, in view of the fact that they can be approached in a cultural context based on historical literature and records, they naturally entail the elements of the Humanities (Mun, 2006). Understanding the contents of the traditional sciences of Korea in terms of the social cultures of the past and reinterpreting them by carefully examining from a modern point of view can pave the way for creative convergent human resources education programs. Korea has a variety of traditional scientific contents, starting with *Chumseongdae* (observation tower of stars) of the 7th century to the traditional rocket of the 15th century; *Singijeon* and *Jagyeokru*, a water clock with automatic time-telling feature; *Geobukseon*, the 16th century iron-clad naval vessel, and the 18th century planned walled fortress city of *Hwaseong* (Mun, 2006; Nam & Son, 2007; KOFAC, 2011). The contents of traditional Korean science selected by the two aforementioned schools, which have adopted the STEAM education model proposed in our study, are *Singijeon* and *Hwacha* (Mapo High School) and also *Hwaseong* and *Geojunggi* (Hana High School). *Hwacha* is a fire vehicle and *Geojunggi* is a cable driving system that was used in constructing *Hwaseong*.

The second goal of this study is to experiment if the method of involving a teacher in charge of the project and enthusiastically engaging in the activities overcomes the essential limit of the student-centered projects. Often, project learning is perceived as a method that relies on students to take the lead in all the stages of a project, such as the selection of a topic, establishment of an activity plan, exploration of an activity, finishing of a stage, etc. Of course, a method where a student self-selects a topic and a problem, afterwards attempting to solve the problem would be most ideal. However, when the accomplishments of a study do not meet the set goals or when an activity stops because of lack of significance, the teacher jumps in and leads the effort in topic selection and study design. The education model proposed in our study is not of virtual project types that are educationally processed similar to the project method and project-based learning. The proposed model entails a direct application of the actual methods that are employed in university research laboratories for projects. In other words, as a university professor carries out projects with students, an advisory teacher executes the actual projects with high school students. This is the model of a method in which the teacher, who designed the project, participates together with students as a co-researcher of equal status. As seen above, the teachers are more active in this model than in the project method that emphasizes the teachers' role as a guide.

WHEEL MODEL OF STEAM EDUCATION

The principle of the Wheel Model

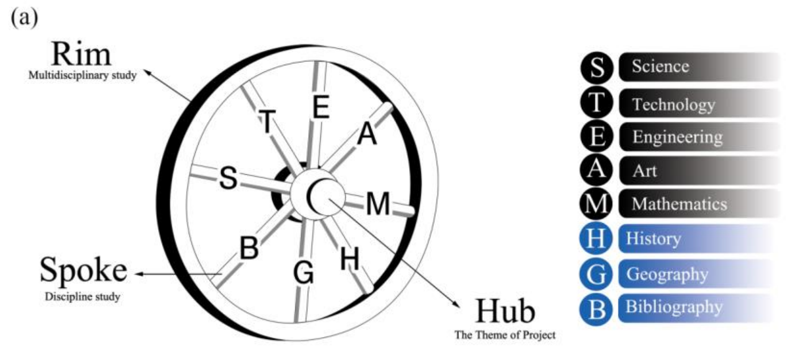
The core principle of the STEAM education model proposed in this study is to use the contents of the Korean sciences as a medium that connects STEAM and the Humanities. This principle is a parallel disciplinary approach method (Lee, 2003), which is designed to take a topic and develop it from the study of eight subjects and, afterwards, while converging them through the process of thesis presentation and discussions, to advance it as a multidisciplinary study. When comparing this model to the elements that comprise a wheel, the central theme would then be the hub, with the discipline studies being the spokes and multidisciplinary study being the rim (Figure 1a).

The reason for such comparison with a wheel is to signify the fact that the compositional elements, originally starting out as one, meet again in a larger framework. The spokes are comprised of the eight spokes that represent the five areas of STEAM and the three additional areas of the Humanities.

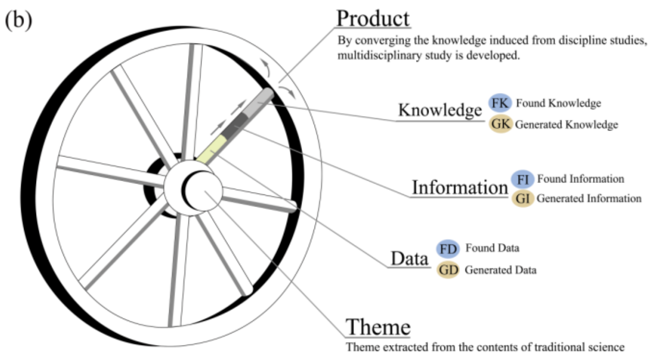
The students become fully knowledgeable of the theme extracted from the traditional Korean scientific contents and, afterwards, by selecting one of the eight discipline studies and while learning during the five-month school term the methods of collecting various data/information, the methods of summarizing and analyzing diverse materials, the methods of preparing reports, etc., they carry out their projects. In the second five-month school term, they communicate the research findings of the team that they belong to with other teams and advance to the stage of a multidisciplinary study.

The wheel model of STEAM education has hierarchized the resulting materials in four stage levels of "data," "information," "knowledge," and "products" for students who are not familiar with projects and the preparation of papers (Figure 1b).

Students develop their projects through the process of data → information → knowledge → product and they experience creating products by knowledge convergence rather than the experience of simply combining the knowledge from various fields. The data levels can be classified as facts that are not processed by someone else and as measured values the students obtain directly through experiments. The former is the found data (FD) and the latter is the generated data (GD). The information levels that are created by processing data can be classified into the found information (FI) and the generated information (GI). The knowledge



(a) The eight discipline studies of the Wheel Model(STEAM & HGB)



(b) The four stage levels in performing project (D→I→K→P)

Figure 1. The Wheel Model Program is composed of eight discipline studies and is conducted with planned project phases performing

obtained through processing information, on the other hand, can be classified into the found knowledge (FK) and the generated knowledge (GK). Dividing the found knowledge and generated knowledge is aimed at separating quotation and argumentation.

The product is something that is obtained by converging the FK and GK of the eight teams through the presentation and discussion of the thesis and by developing into a multidisciplinary study. The representative forms of the product are thesis, research report, model, and video clip.

In the rim stage of the wheel model, it is useful to define and instruct the concept of research thesis as a paper that identifies and describes the sources of FD, FI, and FK by summarizing GD, GI, and GK. According to this definition, although researches that have a clear given and self-creation may be evaluated as high, papers that have the given and created mixed in a blur or are opaque are evaluated as low. As shown, by separating the given and the self-created, objectivism and constructivism may be compromised.

Performing project method

The wheel model of STEAM education proposed in this study can be realized by the Performing Project Method. The Performing Project Method is different from the Project Method and Project-based Learning. The traditional Project Method emphasizes that students should self-plan their learning activities to solve problems (Kilpatrick, 1918; Sexton, 1990). Project-based Learning is a thoroughly designed method for students to learn through projects and it, more so than the Project Method in which a student discovers and solves problems by oneself, entails a more active preparation and participation from a teacher (Thom Markham et al., 2003).

The Performing Project Method is distinguished from these based on the fact that it is not a project that is processed for the purpose of education but for actually carrying out a project in a hands-on fashion. The differences of the Performing Project Method from the Project Method and Project-based Learning can be summarized as follows (Table 1).

First, although Project-based Learning starts out with the students self-discovering the problem, the Performing Project Method starts out with the advisory teacher thoroughly designing a convergent human resources education program. Second, the teacher and students are not separated and the teachers are to participate with the students at an equal level as the Research Manager. The teacher would be the Project Manager (PM), and the Subject Matter Manager (SMM) would be comprised of the Chief Researcher (CR), subject teacher, and outside experts who will support the student researchers. Third, the method is not learner-focused but more of a teacher-student dyad. In Project-based Learning, it is typical for the teacher to transfer the authority given to the teacher over to the students (Table 2).

However, in the Performing Project Method, the teacher does not simply encourage students rather vaguely to continue their research but participates by leading the design of research as the manager of research. In cases of the execution ability of a student researcher being above the targeted level, the advisory teacher can delegate a part of the responsibility of the chief researcher. In addition, when a

Table 1. Characteristics of PM, PBL, and PPM

	Project Method	Project-based Learning	Performing Project Method
Concept	Learning method of project characteristics	Learning method designed for students to learn through projects	Method of carrying out actual projects
Teacher	Guide	Designer / Guide	Research Manager
Student	Designer / Participant	Participant	Co-researcher
Output	Research report, portfolio		Thesis paper, patents, products

project is participated in by superior students, a model in which multiple chief researchers are present is possible. Fourthly, the project's accomplishments are practical. A project in the Performing Project Method is not a simulation for education but a real project in which the school community and even the outside experts participate and that continues for a long period of time. As such, there is a significant qualitative difference in the fact that, unlike the accomplishments of Project-based Learning where they are of a simple report level, the accomplishments of the Performing Project Method become the actual thesis paper or product.

APPLICATIONS OF THE WHEEL MODEL

Case 1: Studies of *Singijeon* and *Hwacha* (2010)

From March to December 2010, at Mapo High School, the studies of *Singijeon* and *Hwacha* were undertaken over two school terms through four hours of regular classes and group activities. Similar to the experimental school of John Dewey that implemented project methods and the Summerhill School of A. S. Niell that implemented inclusive education, the Mapo High School organized and operated a project support team comprised of three teachers as an official department in order to demonstrate applying STEAM curriculums. School projects are operated, including the research design period, in 1-year periods. The Mapo High Schools Project Manager (PM) designed the core theme by taking into consideration national level curriculums, school curriculums, school environment, students' interests, students' social interests, etc., based on questionnaires on the students' interest.

Project design

Singijeon is a solid propellant rocket that uses black gunpowder as accelerant (Figure 2a). Based on the size of the paper gunpowder container, *Singijeon* is classified into *small Singijeon*, *medium Singijeon*, and *large Singijeon* (Chae, 1975). It is known that during the Japanese invasion of Korea in 1592 in the Battle of *Haengju* Mountain Fortress, the divine machine of *Hwacha* carrying 2,300 troops from the Korean military was able to defeat 30,000 Japanese troops (Chae, 1975; Nam & Son, 2007). A fire vehicle is an artillery weapon with ballista contraption capable of launching projectiles (such as arrows and steel bullets) installed onto a wagon (Figure 2b).

The PM sets the theme, which is equivalent to the hub, as studies of *Singijeon* and *Hwacha* question the existing understanding that *Singijeon* and *Hwacha* were useful

Table 2. Staffing for performing project method

Titles	Roles	Responsible Person
Project Manager (PM)	Take charge of Project Design and Management	Advisory teacher
Subject Matter Manager (SMM)	Gives advice on contents for each subject	Subject teacher and outside expert
Chief Researcher (CR)	Serves as the research's team leader	Student representative
Researcher	Carries out projects	Student

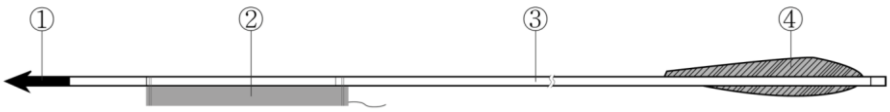


Figure 2a. Structure of Singijeon ① Arrowhead ② Paper gunpowder container ③ Arrow shaft ④ Feather

in wide open fields and were used in close combat situations like the Battle of

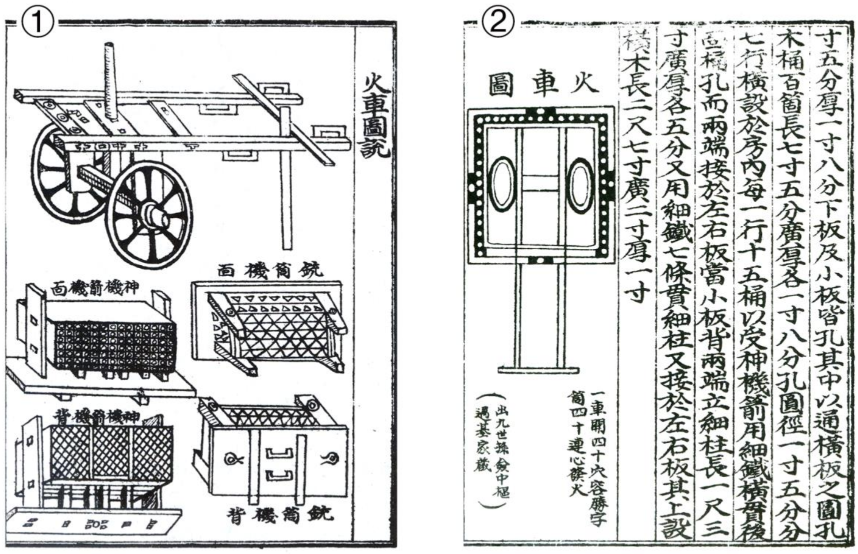


Figure 2b. Structure of *Hwacha* ① *Singijeon-Hwacha* launching 100 arrows ② *Hwacha* used in the *Haengju* Mountain Fortress Battle in 1592

Table 3. Discipline studies contents design (2010 Study Team)

Discipline	Content	Project
Science	Chemistry	Characterization of black powder
Technology	Computer-aided Design	Analysis of *Hwacha* drawings and reconstruction
Engineering	Aeronautical Engineering	Research of *Singijeon* as a rocket-powered flight object
Art	Visual Arts Production	Production of *Hwacha* drawings
Mathematics	Mathematical Statistics	Measurement and analysis of data
History	History of Korea	Composition of the Battle of *Haengju* Mountain Fortress
Geography	Geomorphology	Topographical analysis of *Haengju* Mountain Fortress and model construction
Bibliography	Deciphering an old manuscript	Interpretation of the ancient document *Byunggidoseol* (weapon illustration)

Haengju Mountain Fortress. The eight discipline studies that correspond to the wheel model's spokes were designed considering the studies that validated the existing knowledge and the studies that inferred about the form of *Hwacha* that was actually used, predicated upon the fact that the existing understanding was wrong (Table 3).

Data, information, and knowledge

The eight discipline studies started out with the process of recruiting researcher students who were to participate in projects. When students rushed to certain individual topics, they were encouraged through interviews to move towards other topics and to make adjustments so that a proper number of students would be assigned to each of the subjects. Individual subjects must proceed with advice from the Subject Matter Manager (SMM) comprised of the teachers of disciplines and outside experts. The Chief Researcher (CR) student who represents the eight research teams serves to assist communication between the PM and researcher students. Individual research undergoes a process of creating information based on collected data, and creating knowledge based on the information.

In the science team, research on black gunpowder, the accelerant of *Singijeon*, was conducted. In the technology team, research on reconfiguring the drawings of *Hwacha* in the ancient documents into modern drawings through the use of computer-aided design was carried out. The engineering team undertook the task of analyzing the flight of *Singijeon* by utilizing the basic knowledge of aeronautical engineering. The art team carried out the task of recreating *Hwacha* drawings into 3-D drawings. The mathematics team, through an experiment, measured the flight distance of *Singijeon* based on launch angle and afterwards conducted works to infer this by using equations (Table 4a).

The history team sought and analyzed all the records related to *Singijeon* and *Hwacha* from the Annals of the Choson Dynasty and based on the analysis, they took on the task of reconstructing the Battle of *Haengju* Mountain Fortress, which is known to have used *Singijeon* in the battle, in accordance with the elapsed time. The geography team, through the topography of *Haengju* Mountain Fortress, carried out the task of building a model of the battle conditions at the time of Japanese Invasion of Korea in 1592. The bibliography team conducted the task of interpreting the *Byeonggidoseol* (1474) and *Mangamjip* (Byeon, 1592), ancient documents related to the military event (Table 4b).

Regarding the characteristics of data level, information level, and knowledge level, there are some differences among the teams. In STEAM, mostly, the analysis of the created materials, information, and knowledge was undertaken, and in the Humanities, the validation of the given materials, information, and knowledge was undertaken (Figure 3).

Table 4a. Process of knowledge generation for STEAM (2010 Study Team)

Level		Characteristic	Performing Project
S	Data	**FD**	Public information dealing with black gunpowder which is the source of *Singijeon*
	Information	**FI**	Information about weaponry that uses black gunpowder
	Knowledge	**FK**	Chemical properties of black gunpowder
T	Data	**FD**	Records of drawings of *Singijeon* and *Hwacha*
	Information	**GI**	Construction of drawings for the reproduction of *Singijeon* and its flight
	Knowledge	**GK**	Production of *Singijeon* and flight simulation
E	Data	**FD**	Public information about rocket accelerant
	Information	**GI**	Analysis of movement of solid fuel rocket propellant
	Knowledge	**GK**	Characteristics of *Singijeon* as a flight object
A	Data	**FD**	Public information about Hwacha used during the Koryeo and Chosun Dynasty Periods
	Information	**FI**	Characteristics of the development of *Hwacha*
	Knowledge	**GK**	Construction of drawings for the reproduction of Hwacha appropriate for the development of *Hwacha*
M	Data	**GD**	Flight distance of model *Singijeon* according to launch angle
	Information	**GI**	Modeling according to launch angle and distance
	Knowledge	**GK**	Estimation equation, error of launch angle, and flight distance of *Singijeon*

Table 4b. Process of generation of knowledge for HGB (2010 Study Team)

Level		Characteristic	Performing Project
H	Data	**FD**	Information related to the 1592 Japanese invasion of Korea
	Information	**FI**	Information about battles that used *Singijeon*
	Knowledge	**GK**	Knowledge about Hwacha used in the Battle of *Haengju* Mountain Fortress
G	Data	**FD**	Topographical drawing of *Haengju* Mountain Fortress
	Information	**GI**	Inference that compares the current topography and the topography of 400 years ago
	Knowledge	**GK**	Production of model for the battle circumstances of *Haengju* Mountain Fortress
B	Data	**FD**	Ancient document materials that mention *Singijeon* and *Hwacha*
	Information	**FI**	Detailed information of *Singijeon* and *Hwacha*
	Knowledge	**FK**	Knowledge about gunpowder and weaponry used in the battle of *Haengju* Mountain Fortress

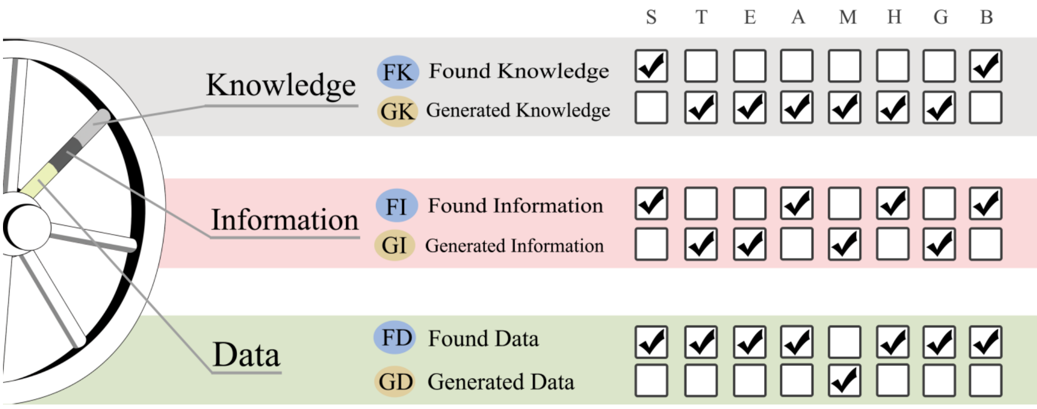


Figure 3. The Checklist of discipline study levels (2010)

Convergence of knowledge

Through the discussion sessions in which the exchange, presentation, and discussion of the summary writings of individual research accomplishments took place, the students criticized the existing knowledge that *Singijeon Hwacha* had been used during the Battle of *Haengju* Mountain Fortress, inferring from and advancing it into a multidisciplinary study that estimated and restored a new form of *Hwacha* that shot in large quantities of small metal projectiles.

In the science team, they identified the fact that, since the burn rate of the black gunpowder could not be controlled en bloc, the variations in the flight distance of *Singijeon* had to be large. The engineering team identified the fact that *Singijeon* could not be sent to desired targets by controlling the launch angles due to *Singijeon* undergoing a complex set of movements where the center of gravity continuously changed during its flight. The mathematics team developed an equation by analyzing the data collected through a flight experiment of the model *Singijeon*, which surmised the relationship between the launch angle and flight distance. However, the attempts to send *Singijeon* to desired spots based on this equation failed. The bibliography team identified the fact that most historical records related to *Singijeon* were associated with the purpose of signaling. By converging the knowledge of the science team, engineering team, mathematics team, and bibliography team, the students reached the conclusion that *Singijeon* was a weapon with a greater functionality of sending signals or scaring off the enemies, rather than imparting direct damages.

The technology team, by analyzing a variety of drawings of *Singijeon Hwacha*, identified the characteristics of direct-fire weapon and indirect-fire weapon. The art team analyzed the uniqueness of *Hwacha* by converting drawings into 3-D drawings. The history team summarized the facts associated with the process and the development process of *Hwacha*, from the times of the Koryeo Dynasty through the Choson Dynasty. The geography team, by restoring the model of *Haengju* Mountain Fortress based on its topography, made inferences that actual battles were concentrated in the small flat areas. By converging the knowledge of the technology team, art team, history team, and geography team, the students reached a conclusion that in the battle of *Haengju* Mountain Fortress, *Hwacha* that fired *Singijeon* was not used.

Based on such conclusions, the research work, resulting from the united efforts of the science team, technology team, engineering team, art team, mathematics team, history team, geography team, and bibliography team and inferring the form of *Hwacha* that was actually used in the Battle of *Haengju* Mountain Fortress, culminated in the restoration of the form of *Hwacha* that fired 40 weaponries of gunpowder.

The history team and bibliography team summarized accurate drawings of *Hwacha* that were actually used in *Haengju* Mountain Fortress by tracking down historical records. The geography team investigated areas of high elevations that had high possibilities of placing *Hwacha* based on the *Haengju* Mountain Fortress terrain model that they produced. The technology team created the drawings of *Hwacha* based on various hypotheses, while the art team took on the responsibility of the design task for restoring these. The science team estimated the amount and energy of black gunpowder needed to launch 40 projectiles. The engineering team, by evaluating the effective range of projectiles, estimated the actual arrangement gaps. The mathematics team calculated the manpower needed to operate 40 units of *Hwacha,* along with its operational plans, with considerations given to certain factors like reloading time. The *Hwacha* was used in the Battle of *Haengju* Mountain Fortress and, through the process of presenting and debating over various hypotheses, the *Hwacha* was restored after the most rational hypothesis was selected (Figure 4).

As they carried out multidisciplinary studies, the research team of students from Mapo High School took pride in restoring for the first time ever the *Hwacha,* which was subjected to the validation of the Korean History of Science Society (Journal for the History of Science). The product was afterwards introduced during a news broadcast of the KBS on September 5, 2011 (see Appendix 1).

Case 2: *Hwaseong* and *Geojunggi* Study (2011)

Project design

From March to December 2011, over two school terms through 4 hours of regular weekly classes and group activities at the Hana High School, a study on *Hwaseong* and *Geojunggi* that applied STEAM education model was conducted. As a UNESCO World Heritage site, *Hwaseong* was a modern walled fortress city that had been planned as a 10-year construction project but, surprisingly, it was completed in just a little over 2 years (Figure 5).

After fortification, the *Hwaseong Songyouk Eugye* [華城城役儀軌], which was published in 1801, recorded in detail the site's fortification plans and systems and forms and rules, along with information on the people involved in its construction,

Figure 4. A reenactment scene for demonstration created by the study

Note. Although at first a configuration of armored vehicle that fired projectiles in three directions was deduced with repeated studies and experiments, the vehicle was modified to a configuration of installing the firing frame at the time of the attack.

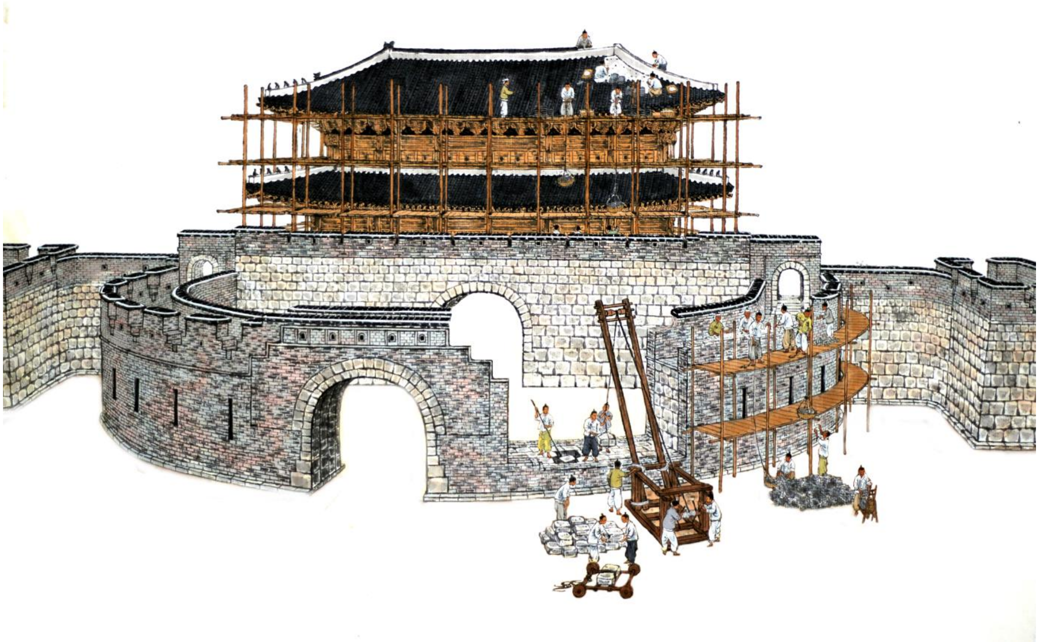


Figure 5. *Hwaseong* entry gate construction (Imaginary Depiction)

Table 5. Discipline studies content design (2011 Study Team)

Discipline	Content	Project
Science	Physics	Analysis of the mechanical power of *Geojunggi*
Technology	Computer-aided Design	Drawing analysis and reconfiguration of construction equipment
Engineering	Civil Engineering	Analysis of the fortress walls and facility structures of *Hwaseong*
Art	Visual Arts Production	Depiction of scenes where *Geojunggi* was used and process of fortress wall construction
Mathematics	Mathematical Statistics	Quantitative analysis and estimation of construction workers' wages for *Hwaseong*
History	History of Korea	Social and cultural analysis of the King *Jeongjo* era of the late Choson Dynasty period
Geography	Geomorphology	Analysis of fortress walls and topography of *Hwaseong*
Bibliography	Deciphering an old manuscript	Translational analysis of *Hwaseong Songyouk Eugye*

the source and usage of materials, the budget and wages, the construction machinery, the material processing methods, the construction journals, etc., thereby leaving a significant footprint in the history of Korean architecture (King Jeongjo, 1801). The historical value of these records is considered significant as well (Kim, 2002; Mun, 2006). In Korea, the role of *Geojunggi* has been highlighted enough to the point that it is described in textbooks as being accountable for the rapid construction of *Hwaseong* (Kim, 2002; Lee, 2008).

Data, information, and knowledge

The PM at the Hana High School questioned the existing knowledge that *Geojunggi* was used in the construction of fortress walls and, with a premise that such existing knowledge was wrong, designed a study that analyzed the actual reasons as to how *Hwaseong* was constructed so rapidly (Table 5).

The science team conducted a study to analyze mechanical power through evaluating the structure of *Geojunggi*. The technology team, through a computer-aided design, undertook the task of reconstructing the construction equipment seen in the ancient documents into modern-day drawings. The engineering team, by utilizing basic knowledge in the civil engineering field, carried out the task of analyzing the structures of fortress walls and defense facilities. The art team took on the task of completing drawings that depicted the operation of *Geojunggi* and construction scenes. The mathematics team quantified and analyzed the wages paid to the construction workers of *Hwaseong* and other construction costs (Table 6a).

The history team conducted the task of analyzing the society and culture during the King *Jeongjo* era. The geography team carried out the task of analyzing and creating a model for the nearby area topography of *Hwaseong* and the fortress wall line. The bibliography team performed the task of analyzing the translated versions of the *Hwaseong* Songyouk Eugye (*Hwaseong* construction report). (Table 6b).

Convergence of knowledge

Through discussion sessions of the students who participated in the discipline studies, in which the exchange, presentation, and discussion of the summary writings of individual research accomplishments took place, the students criticized the existing knowledge that *Geojunggi* had contributed to reducing the construction time of *Hwaseong*.

The science team argued persuasively that it would have been impossible to construct all the fortress walls and facilities of *Hwaseon*g with *Geojunggi*. The technology team identified the efficiencies of the construction equipment used in the

Table 6a. Process of knowledge generation for STEAM (2011 Study Team)

Level	Characteristics	Performing Project
S-Data	**FD**	Data that explains the structure of *Geojunggi* and the type, size, and weight of stones used in the construction of Hwaseong
S-Information	**GI**	Power of *Geojunggi* according to stone types
S-Knowledge	**GK**	Total power of *Geojunggi* used in the construction of Hwaseong
T-Data	**FD**	Construction equipment drawings used in the construction of *Hwaseong*
T-Information	**GI**	Construction drawings of construction equipment
T-Knowledge	**GK**	Simulation of construction equipment
E-Data	**FD**	Public information related to the structure of fortress walls
E-Information	**FI**	Difference between the fortress walls of *Hwaseong* and other fortress walls (those of the West, Japan, and China in a similar period)
E-Knowledge	**GK**	Structural characteristics of *Hwaseong* fortress walls
A-Data	**FD**	Public information related to the usage scenes of *Geojunggi* (model, imagined drawings)
A-Information	**GI**	Process of construction of fortress walls utilizing a bevel slope
A-Knowledge	**GK**	Creation of drawings depicting the construction of fortress walls without the use of *Geojunggi*
M-Data	**FD**	The number of days and the wage data of the construction workers of *Hwaseong*
M-Information	**GI**	Modeling of the specialization of labor and individual differences
M-Knowledge	**GK**	Uniqueness of the wage payment method of the construction workers of *Hwaseong*

Table 6b. Process of knowledge generation for HGB (2011 Study Team)

Level	Characteristics	Performing Project
H-Data	**FD**	Materials that mention the social culture of the King Jeongjo era
H -Information	**FI**	Information related to the construction of *Hwaseong*
H -Knowledge	**FK**	Knowledge about the capitalistic economy
G-Data	**FD**	Topographical drawings of *Hwaseong*
G-Information	**FI**	Comparison of today's topography and the topography at the time of the construction of *Hwaseong*
G-Knowledge	**GK**	Production of the walled city model of *Hwaseong*
B-Data	**FD**	*Hwaseong Songyouk Eugye*
B-Information	**FI**	Summary of contents of the translated versions of *Hwaseong Songyouk Eugye*
B-Knowledge	**GK**	Commonization of vocabulary that is different in translated versions of *Hwaseong Songyouk Eugye*

construction of *Hwaseong* by calculating mechanical power which was not that high. The engineering team argued that the construction of the fortress walls of *Hwaseong* relied on methods that utilized the slope of bevel surfaces by using various construction carts. The art team depicted the construction sites of *Hwaseong* with a variety of drawings. The mathematics team demonstrated that at the construction sites of *Hwaseong,* an efficient human resource management using performance-based wages was taking place. The history team identified that at the time of the construction of *Hwaseong,* the society was changing from an agricultural to a capitalistic one. The geography team argued that the distance between the regions where the construction materials for *Hwaseong* came from and the construction sites was quite far. The bibliography team, by analyzing the *Hwaseong* Songyouk Eugye, proved that not a single *Geojunggi* had been used and it identified the fact that most of the various construction equipment used was dependent on human power.

They secured the grounds for their argument supporting the hypothesis that one *Geojunggi* wouldn't be enough to meet the construction deadline through discipline studies. Instead of the existing crane hypothesis (Figure 6a), they argued for the stacker hypothesis that the *Geojunggi* was used mainly for loading heavy stones onto

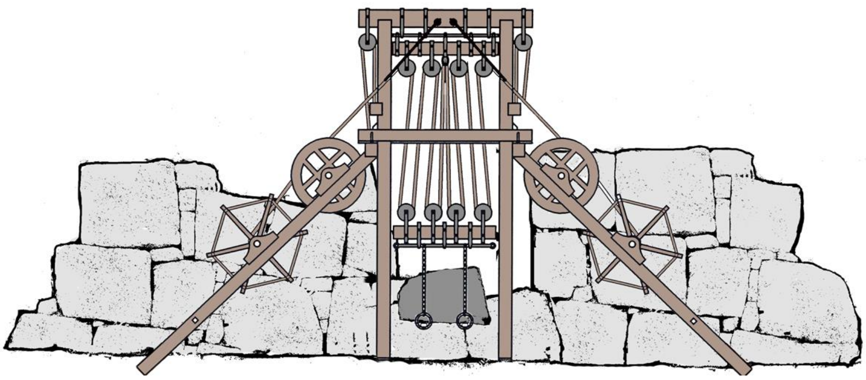


Figure 6a. *Geojunggi* was used in the construction of fortress walls

Note. This is a painting done by the art team, which shows the existing knowledge that Geojunggi was used in the construction of fort ress walls by putting rocks directly on the spot.

Figure 6b. *Geojunggi* was used as a stacker for loading stones

Note. Only one Geojunggi unit was used in the construction and it was used as a stacker for loading stones onto construction carts he aded to the construction site.

construction carts (Figure 6b).

Using the status of the transport equipment and work progress that were included in the *Hwaseong Songyouk Eugye* as the basis, they proposed a detailed process of fortress wall construction that was done without using *Geojunggi*.

Based on the conclusion attained through the multidisciplinary study, they asserted that the real reason for being able to reduce the construction time of *Hwaseong* was that the limited construction equipment had been efficiently allotted and the human resource was efficiently managed. The research accomplishments of the study team at Hana High School were featured on the September 19, 2011 KBS news after undergoing a validation by the Korean Society of Civil Engineers (See Appendix 2).

DISCUSSION

Today, the development of a new theory or technology is often accomplished through projects where multiple studies converge rather than through individual research in one field (Sanders, 2009). The education model proposed in our study entails having high school students participate as co-researchers in carrying out actual convergent projects, and is based on the wheel model in which the contents related to high school curriculums are reflected and the convergence of knowledge is emphasized.

This study has proposed a form of project execution method, the purpose of which is to supplement the permissive type of project-based learning of letting the student pursue whatever subject he/she wants to pursue by having the teacher get involved as the research manager who designs projects and carries out joint-research together with students. The students experience the process of solving problems as they exchange opinions in a logical manner and rebut differing opinions.

The abilities that students can nurture for themselves through the STEAM education model are the ability to analyze topics, the skill to collect materials pertinent to topics and construct information, the capability to develop information up to the level of knowledge, and the competence to create new ideas by converging knowledge. The improvement on the grades of the 60 students from the two schools participating in the project was remarkable, with 53 students except 7 being admitted to the departments of the universities related to their project team through the admission type which evaluated the applicant through grade reports and project performances. The student satisfaction was significantly high (Figure 7a).

Students took part in the project of the two schools and evaluated the project as helpful on communication ability improvement and career exploration. The Mapo and Hana High Schools are sustaining the project, changing the subject and the teams on an annual basis, and many schools are conducting similar projects benchmarking this (Figure 7b).

The cases of Mapo High School and Hana High School, which were verified by the academia and after which were introduced on the KBS news, can be utilized as learning materials that provide information for the nature and procedure of other projects and one providing motivation to future study teams.

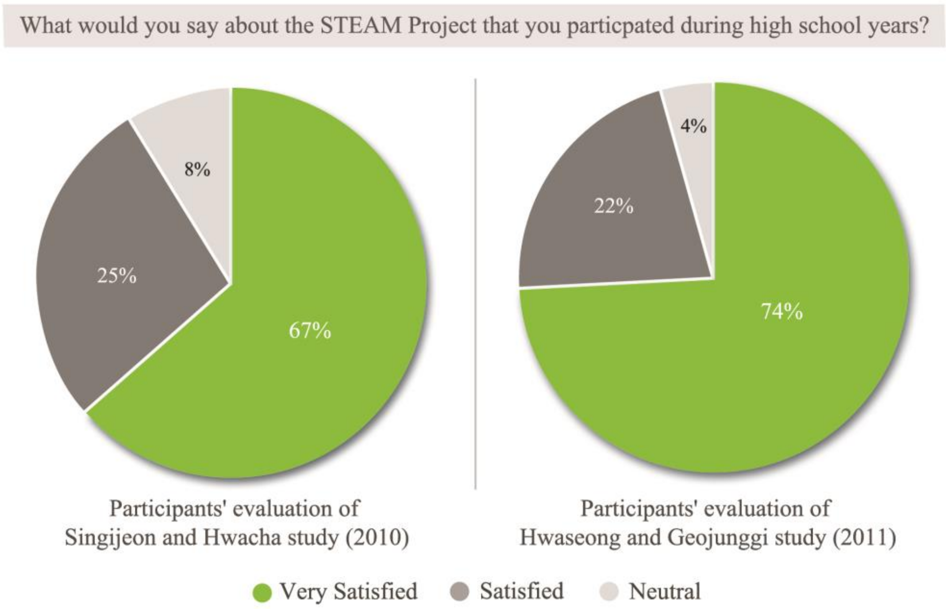


Figure 7a. The student satisfaction in the STEAM Project

Note. This is the Retrospective survey result, targeting the students who took part in the projects in January 2014, 2010, and 2011. 35 students out of 60 responded to the survey.

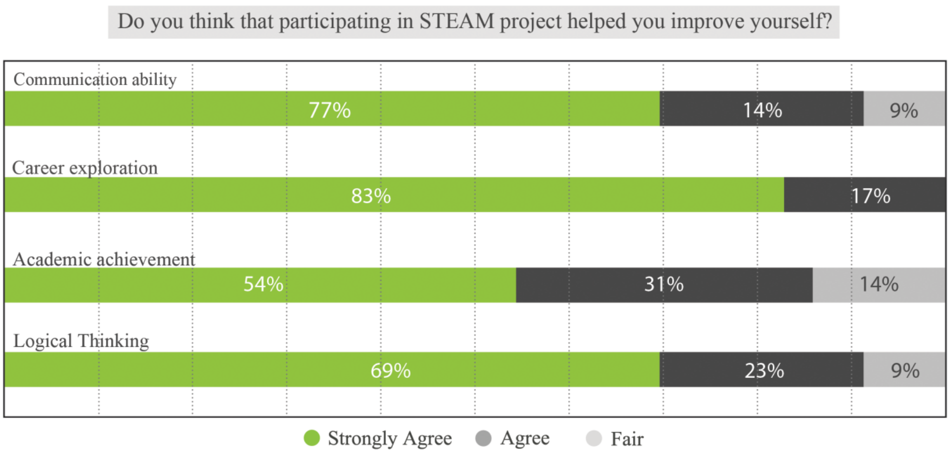


Figure 7b. Effectivity of the STEAM Project

In order for the education model proposed in this study to become vitalized, the following institutional support systems are required. First, educational journals with credibility that would target students who could present their accomplishments from projects are needed. Currently, other than registering for patents, there are almost no journals that recognize middle school or high school students as authors, and this causes many papers written with much effort to die out. Second, there need to be a variety of support systems that provide research funds for research expenses on projects. In many cases, the estimates of research expenses of research teams that are comprised of student researchers are realistically relied upon and done by the advisory teacher, and, based on the benefit principle, most of the research expenses fall on being the burden of the students' parents. By reasonably assigning the budgets of local schools, various models that can support student projects would need to be proposed. Third, a system that supports advisory teachers who manage these projects needs to be established. In addition, along with the growing of the competence of teachers who can manage projects, the fostering of groups of experts who can consult on projects designs is needed as well. Now, as the 2009 curriculum reform is being implemented in Korea, a sizable portion of authority for curriculum design and operation has been moved to the local schools at the national level (KMOE, 2009). The time has come in which the challenges and efforts of the local school teachers, who want to directly design various projects that are appropriate for the circumstances of local schools, are needed.

However, there are limitations that this study did not take into account. Due to privacy, it couldn't present organized quantitative data, which described the specific improvement of the students who participated in the project, and grades data, which could prove the participants' progress. There should have been a system that could organize and report the process of the research of the students systemically. Second, specific and detailed discussions on the heavy workload on the teacher conducting the research team were deficient. In order to alleviate the heavy workload of teachers teaching along and having to serve as project managers, a support system that allows the use of various outside experts as curriculum managers would need to be established. A follow-up study may address these issues in one way or another.

In conclusion, The STEAM Education based on the wheel model is meaningful in that it enables experiencing academic research and creating a certain product while carrying out a project. Along with the above, the Performing Project Method carries the advantage of the teacher and students cooperatively forming an outcome and overcoming the essential limits of a student-centered project.

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APPENDIX 1: Overview of *Singijeon* and *Hwacha* Study (2010)

http://youtu.be/f2dbr383Lxk

Existing Knowledge	● In the Battle of Haengju Mountain Fortress, the Choson army composed of 2,300 soldiers defeated 20,000 Japanese troops. ● In the Battle of Haengju Mountain Fortress, *Singijeon* was used. ● The Koreans were victorious in the Battle of Haengju Mountain Fortress because of the *Singijeon* and *Hwacha*.	
Issues Raised	● Would *Singijeon Hwacha* have been effective in close battle situations? ● If not, what were the reasons for the victory in the Battle of Haengju Mountain Fortress?	
Creation of Knowledge	**S**	The variability in the flight distance of *Singijeon* was inevitably large.
	T	The design of *Singijeon Hwacha* was susceptible to damage by indirect-fire weaponry.
	E	*Singijeon* could not be used to send projectiles to desired target areas by adjusting launch angles.
	A	The design of *Hwacha* used in the Battle of Haengju Mountain Fortress was susceptible to damage by direct-fire weaponry.
	M	Modeling for launch angle and flight distance is not feasible.
	H	Summary of the development process of *Hwacha* during the Choson Dynasty era (indirect firing → direct firing)
	G	Estimation of the use of direct-fire weaponry based on the results of restoring the topography of Haengju Mountain Fortress by using a model
	B	All the historical records related to *Singijeon* indicate the purpose of signaling.
Convergence of Knowledge	● In the Battle of Haengju Mountain Fortress, *Singijeon Hwacha* was not used. ● *Hwacha* that was capable of firing 40 projectiles accounted for the victory at the Battle of Haengju Mountain Fortress.	
Product	● Research (thesis paper) of *Hwacha* used in the Battle of Haengju Mountain Fortress ● Restoration (actual model) of *Hwacha* used in the Battle of Haengju Mountain Fortress	

APPENDIX 2: Outline of *Hwaseong* and *Geojunggi* Study (2011)

https://youtu.be/DS0qGy-8IqA

Existing Knowledge		● *Hwaseong* was planned for a 10-year period construction but it was completed in 3 years. ● *Geojunggi* was used as construction cranes in the construction of fortress wall. ● The rapid construction of *Hwaseong* was because of *Geojunggi.*
Issues Raised		● Was *Geojunggi* effective in constructing fortress walls? ● If there were no such effects, what accounted for the rapid construction of *Hwaseong*?
Creation of Knowledge	**S**	It was not possible to erect all the fortress walls with just one *Geojunggi.*
	T	*Geojunggi* caused the efficiency of the construction of fortress walls to decrease.
	E	The fortress walls of *Hwaseong* were not of a structure that could be erected with *Geojunggi.*
	A	It is possible to depict step-by-step the process of erecting fortress walls without using *Geojunggi.*
	M	The number of days worked and wages of construction workers used in the construction of *Hwaseong* were large in terms of variability.
	H	At the time of the construction of *Hwaseong*, capitalism was being formed in Choson.
	G	The nearby sources that could supply stone materials for the construction of *Hwaseong* were limited.
	B	Based on the study of pertinent literature, the construction of *Hwaseong* relied mostly on manual labor.
Convergence of Knowledge		● In the construction of the fortress walls of *Hwaseong*, *Geojunggi* was not used. ● The rapid construction of *Hwaseong* was attributable to the innovation of management that efficiently managed limited construction equipment and labor sources.
Product		● Construction of *Hwaseong* and management innovation (thesis paper) ● Construction process drawings of fortress walls of *Hwaseong* (Oriental paintings)