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Engineering Design: A Facilitator for Science, Technology, Engineering, and Mathematics [STEM] Education

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공학적 디자인: 과학, 기술, 공학, 수학교육의 촉진자

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국문 요약

이 연구의 목적은 과학, 기술, 공학, 수학(STEM) 교육의 다양한 통합적인 노력 중에서 기술과 과학 교육 분야 전문가들이 수행한 디자인 관련 연구들을 고찰하는데 있다. 33개의 통합교육관련 논문들을 선별하여 메타연구와 질적인 내용 분석을 통하여 분석하였다. 연구 결과를 정리하면 다음과 같다. 디자인은 다양한 용어로 사용되고 있으며 다양한 접근방법을 통해 과학과 기술교육분야에 이용되고 있다. 공학적 디자인을 이용한 과학 개념의 학습은 최근 중요하게 다루어지고 있는 주제이며, 인지적, 정의적인 측면에서 효과가 있는 것으로 나타났다. 아울러, 공학적 디자인은 기술교육에 있어 최근 주요 연구 방향으로 제시되고 있으며, 기술교육과 공학교육을 연결할 수 있는 방법을 제공하고 있다. 공학적 디자인을 이용한 교육방법은 학생들의 학습향상과 동기유발에 도움이 되고, 협동학습과 진로교육에 긍정적인 효과를 보여주는 것으로 나타났다. 통합교육에 관한 인식의 부족으로 공학적 디자인을 이용한 과학, 기술, 공학, 수학교육의 효과를 검증하는 연구가 부족한 실정이다.

주요어: 공학적 디자인, 기술교육, 과학교육, STEM 교육

I. Introduction

The significance of Science, Technology, Engineering, and Mathematics (STEM) education has increased from K-12 education to the national level. National science, mathematics, and technology education professional associations in the United States are united in their support for integrating STEM areas. The emergence of a variety of efforts to integrate STEM disciplines is quite noble for students, teaching experts, and the education environment. In other words, the importance and value of STEM education results from the needs of the learners, society, and government.

With rapid educational transitions, educational communities have endeavored to search for their unique strategies to establish the rationale for their disciplines. STEM education should also establish its rationale to have credibility and recognition from the public. To obtain a robust place in general education, STEM education should possess its methodology and pedagogy. Although many scholars in the field of STEM education have searched for its rationale to implement in general education, an exemplary method or strategy to implement STEM education has not been studied yet.

The *Standards for Technological Literacy* (International Technology Education Association [ITEA], 2000) publication addresses the centrality of design to implement technology education. Design has been considered the major problem-solving process of technological development. In

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other words, technology education has been heavily involved in the problem solving process than other disciplines and technology educators have emphasized technological design activities as one major technology activity or methodology of technology education. Historically, these design activities have been one of the major methodologies or strategies in technology/engineering education. The Accreditation Board for Engineering and Technology (ABET) mentions that engineering design is "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs" (2007, p. 21).

Recently, science education has become interested in design pedagogy and methodology. Science educators believe in the importance of design and technological literacy in the implementation of authentic science education. *Benchmarks for Science Literacy* describes the significance of design and the undeniable relationship between science and technology (American Association for the Advancement of Science [AAAS], 1993). Even though inquiry is the signature pedagogy of science education, science educators are beginning to employ design pedagogy in their science classes. Design is a form of problem solving in which thinking, tool manipulation, and materials are reflected in the construction of an artifact (Roth, 2001).

These recent trends of technology education and science education have led them both to employ a variety of design components such as engineering/technological design, design process, and design loop in their teaching implementations. For these reasons, pedagogical or methodological approaches that employ the design components in their teaching are most appropriate for the implementation of STEM education. This study employs the definition of STEM education as an integrative curriculum model that seeks to make connections among STEM disciplines through the use of open-ended and real world problems (Drake & Burns, 2004; Sanders, 2006; VT Technology Education, 2006). The definition focuses on the integrative characteristic of STEM education. It is possible that technological content and/or technological process based on hands-on activities play a significant role in integrating and connecting STEM areas. The purpose of this study is to investigate "What are key common topics identified and discussed in relevant literature associated with the integrative efforts among STEM disciplines?" This study introduces several characterized trends and cases of integrating STEM disciplines through reviewing relevant literature. To achieve the purpose of this study, the following specific research questions are established.

1) What is the key methodology and pedagogy presented in literature associated with the integrative efforts among STEM disciplines?

2) What are the significant benefits of using the design method for STEM education?

Ⅱ. Research Procedure

This investigation was performed in two phases. One was the establishment of a research background for the main study and included a process of collecting relevant literature regarding the integration among STEM disciplines. This phase was conducted by two screening procedures.

The first step was to search for relevant literature from 1999 to 2008 through the Education Resources Information Center (ERIC) database as of 15 August 2009. The authors used various combinations of the following searching words through the library database of *Virginia Polytechnic Institute and State University* and *Utah State University* respectively: "integration", "interdisciplinary", "multidisciplinary", "science", "technology", "engineering", "mathematics", "integrative efforts", "STEM education", "technological design", "engineering design", "scientific inquiry", "integrated curriculum", "integrated instruction" 194 research papers were selected in the first process.

The second step was to screen 194 research papers authors selected by three concentrations: 1) empirical data related to the integrative effort among STEM disciplines, 2) evident method or strategy to integrate STEM disciplines, and 3) K-12 students' learning. Also, two researchers scrutinized the title and abstract respectively, discussed the relevance to this study, and made a consensus as the targeted research articles. It was a necessary procedure for research reliability to make a consented list for the investigation. Finally, this study had 33 research papers for identifying the key methodology that integrated STEM areas. Additionally, 24 papers focused on the conceptual research were used to establish a theoretical background for this study.

The overall research procedure followed a systematic approach to identify key methods and the characteristics for the integrative efforts among STEM disciplines. This study concentrated on obtaining, utilizing, and synthesizing the major findings and conclusions of the 33 empirical research papers. This qualitative approach to meta-analysis has been successfully employed in the field of social science (Petrina, 1998).

Ⅲ. Key Features of the Relevant Literature

All 33 research papers indicated empirical data associated with the integrative efforts among STEM areas. Basically, these papers were distributed into diverse journals based on one or more backgrounds of "science education", "technology education", "engineering education", and "mathematics education". As presented in Table 1, three journals of "*Journal of Research in Science Teaching*", "*Journal of Industrial Teacher Education*", and "*International Journal of Design and Technology Education*" have issued empirical research that integrated STEM areas indicating four journal papers respectively. And a variety of journals of "The Technology Teacher", "Science and Children", "International Journal of Science Education", "The Journal of the Learning Sciences", etc have been interested in investigating the empirical evidence related to the integration among STEM areas.

The key authors who have studied the integration among STEM areas and endeavored to investigate the empirical evidence regarding the benefits and gains of integrating STEM areas were "*Kolodner*" (3 journal papers), "*Puntambekar*" (2 journal papers), "*Schunn*" (2 journal papers), and "*Doppelt*" (2 journal papers).

The names described in 33 research papers as key methods to integrate STEM areas were various as shown in Table 2. "*Technological/Engineering design*" was dominantly employed as a means to integrate STEM subjects. Within a context of technology/engineering design, design challenge or competition was frequently used in many studies (De Romero, Slater, & DeCristofano, 2006; Fitzgerald, 2004; Huchinson, 2002; Pliskow 2008) Also, "*Design Based Learning: DBL*" (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009) and "*Learning By Design: LBD*" (Kolodner, 2002) in the field of science

Table 1 A list of the Journals on the Integration among STEM Areas

Journal Name	Number of Papers
Journal of Research in Science Teaching	4
Journal of Industrial Teacher Education	4
International Journal of Design and Technology Education	4
The Technology Teacher	2
Science and Children	2
Other Journals	17

education were frequently used in 9 different studies. Interestingly, Lewis (2006) suggested "*Design and Inquiry method*" as a methodology or pedagogy to integrate STEM subjects.

In summary, there are the key research trends that have studied the integration among STEM areas. The investigation regarding the integrative efforts among STEM areas was performed across diverse journals based on "Science Education", "Technology Education", "Engineering Education", and "Mathematics Education". The most prevalent method to integrate STEM subjects was technological/engineering design. In the field of science education, names such as DBL or LBD were frequently used. With this in mind, this study investigates the design methodology deeply.

Ⅳ. A Methodology and Pedagogy for STEM Education

Several studies have been conducted on the effectiveness of integration among STEM subjects. These studies were started from the lack of research on curriculum integration and the limitations encountered by researchers. LaPorte and Sanders (1995) suggested an exemplary model to integrate technology, science, and mathematics. In the study, they are focused on hands-on science and integration related to technology, science, and mathematics. Using this program, Childress (1996) had a quasi-experimental study that tried to determine if the integration program improve the technological problem solving ability. This section offers a detailed description regarding the tools to integrate STEM subjects. Key methods addressed in the prior studies are technological/engineering design, design based learning (DBL), learning by design (LBD), design and inquiry, etc.

1. Technological/Engineering Design

In the historical perspective of technology education, there have been several efforts to establish a rationale for technology education. Publications such as *Technology for all Americans: A Rationale and Structure for the Study of Technology* (1996), *Standards for Technological Literacy: Content for the Study of Technology* (2000), and *Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards* (2003) would be the examples of these efforts. Although technology educators have taken efforts to engage the public in the study of technology leading to the goal of technological literacy, technology education faces a critical problem. There has been little practical improvement in most technology education programs in public schools (Wicklein, 2005). Wicklein (2006) suggests that by organizing the technology education high school curriculum to be associated with engineering design, technology education will be able to solve this problem and achieve the goal of technological literacy. Also, Wicklein (2006) suggests that this would benefit technology education in the following ways:

1) Engineering design is more understood and valued than technology education by the

Table 2 Methods to Integrate STEM Area

Names Used as a Means to Integrate STEM areas	Number of Papers
Technological Design or Engineering Design	15
Design Based Learning (Design Based Science)	5
Learning by Design (Learning by Design Artifacts)	4
Scientific Inquiry (Reasoning, Experimental Process)	3
Design and Inquiry	3
Other Names (Mathematical Modeling, Using Technology)	3

general Populace

2) Engineering design elevates the field of technology education to higher academic and technological levels
3) Engineering design provides a solid framework to design and organize curriculum
4) Engineering design provides an ideal platform for integrating mathematics, science, and technology
5) Engineering provides a focused curriculum that can lead to multiple career pathways for students (p. 27).

In the international perspective, design process has been unique idea to implement British technology education. Other countries, especially Europe and the United Kingdom and Australia have more extensive and mature technology education programs than the U.S. In the U.K., technology education has evolved over time with priority given to problem solving, the design process, or both (Hutchinson, 1986; Wright, 1993). In 1990, the U.K. government implemented a new technology education program called 'design and technology' as one of the subjects in the national curriculum.

National standards of technology education are largely categorized into five chapters titled: "Nature of technology," "Technology and society," "Design," "Technological world," and "Designed world" (ITEA, 2000). Design in technology education has been emphasized and fundamental to the study of technology. ITEA(2000) refers to design as "the creative soul of technology" and emphasizes the value of design in technology education. The standards related to design are as follows:

1) The attributes of design
2) Engineering design
3) The role of trouble shooting, research and development, invention and innovation, and experimentation in problem solving
4) Apply the design process (p. 15)

National, state, and district K-12 education standards indicate the need to prepare all students to live and work in a technological world to achieve technological literacy. The standards establish the goal for students to go beyond understanding design to develop design capability. Students develop capability through chances to engage in solving technological problems and to reflect on the problem, process, and solution (Leonard, 2004).

In the perspective of STEM education, technological/engineering design provides a way to integrate the science, technology, engineering and mathematics disciplines (Satchwell & Loepp, 2002; Venville, Rennie, & Wallace, 2004; West, Tooke, & Muller, 2003; Zubrowki, 2002). In the design process the linkage of these disciplines is present. The response to a request for input pertaining to the coming science assessments in 2009 contains a significant issue for technology education. Technological design plays important roles to teaching and learning of science education as well as technology education. Technological design helps students adjust to change, deal with forces that influence their lives, and to participate in controlling their futures using science knowledge as a basis for action. Zubrowski (2002) suggested a possible way that would integrate scientific content into the process of student learning technological design. According to his model, there are three phases of brainstorming, preliminary construction, and open design process. The brainstorming is an open exploration during which students are free to try out their own ideas attempting to build something that is functional but usually not very efficient. The preliminary construction involved the adoption of what can be called a standard model. This is used to carry out systematic testing of essential variables of the system. The open design process is a return to the design process, using the newly gained knowledge to rebuild and make a more effective design. Furthermore, integrated curriculum is characterized into four basic categories. One of the pedagogical models is a deliberate and explicit combination of design and inquiry. In his study, the comprehensive context is a design project. Designing and building a working model of technological artifact challenge students. For example, a flying toy, windmill, water wheel, or balloon-propelled car, with a limited set of material initial performance criteria are able to be employed in the K-12 science or technology classes. The preliminary models designed and tested are changed into a standard model used to carry out inquiry.

2. Informed Design

Although technological design problems are rarely well defined in the classroom settings, well defined problems are prevalent and then students have little experience with open-ended problems. With this recognition, Burghardt and Hacker (2004) stress pedagogical rationale for design and informed design. Informed design is a pedagogical approach and enables students to improve their own related knowledge and skill base before striving to suggest design solutions. Through informed design, students design solutions "informed" by their knowledge and research. In the context of informed design, the challenges to improve design performance include math and science. This challenge accelerates the research, inquiry, and analysis. Burghardt and Hacker (2004) propose an informed design cycle as follows:

1) Clarify design specifications and constraints. Describe the problem clearly and fully, noting constrains and specifications.
2) Research and investigate the problem. Search for and discuss solutions to solve this or similar problems
3) Generate alternative designs
4) Choose and justify optimal design
5) Develop a prototype
6) Test and evaluate the design solution
7) Redesign the solution with modifications
8) Communicate your achievements

Through the cycle, students are able to delve into the mathematics, science, or other skills for the design.

3. Design and Inquiry

Interestingly, technological design and scientific inquiry were used as a tool to integrate STEM subjects in several studies (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Hutchinson, 2002; Parkinson, 2007). Design is being employed in classrooms in ways that are bringing science and technology education closer together (Lewis, 2006). Reforms for better science education are calling for more hands-on, active problem solving strategies design could play a vital role. He illustrates examples of teaching science through design in science education and design through science in technology education. Even though design and inquiry diverge in their purposes, Lewis (2006) discusses several convergences between inquiry and design. Both are reasoning processes and contain searching (brainstorming, analogical reasoning, researching), visualization (graphics, models), testing, decision-making (alternative, date compare to hypothesis), content knowledge (science, physics, mathematics, materials), constraints (cost, safety, environment, ethics), trials and error, reflections, and learning from failure. Apedoe, Reynolds, Ellefson, and Schunn. (2008) infused engineering design into K-12 science classroom setting. They employed "*Design Based Learning*" combining scientific inquiry and engineering design to meet both K-12 educators' and engineering advocates' goals.

4. Design Methods in Science Education

More recently, many science educators in the U.S. have started to employ engineering design concepts in their classrooms for improving science learning, supporting general problem solving skills, and encouraging team work as Design Based Learning (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Maaman, 2005;

Perrenet & Adan, 2002). Particularly, design concepts and principles in national science standards speak to the emerging view of experts in the science, technology, and education fields that an understanding of design is complementary with and supportive of science literacy (Cajas, 2001; National Council of Teachers of Mathematics [NCTM], 2000). Also, engineering design is employed to provide a real-world context for science. The curricular developers use designs as an impetus for learning science. For example, as a means to facilitate students in acquiring scientific knowledge and skills, engineering design is employed by the science educators. In science education, the employment of a design-based curriculum provides a meaningful context in teaching science and has implications as a viable alternative for teaching science reasoning (Doppelt, 2009; Leonard, 2004). In design-based science curricula, design is referred to in the sense of engineering or technological design, that is, the construction of an artifact to solve an identified need. "*Design-Based Learning* (DBL)" is a special case of problem or project based learning. Inquiry-based curricula in science education often incorporate design projects.

In addition, the instructional methods typical in design-based science curricula also have particular appeal to the learning of science. DBL also has considerable alignment with contemporary theories of learning such as active learners and meta-cognitive strategies from self-monitoring and reflection (Doppelt, 2009; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Maaman, 2005). Traditionally, inquiry has been the major pedagogy of science education. However, science educators strive to use the design-based learning in their science classes. Design-based learning is designed to engage students in ways that improve their abilities to solve real-life problems and to reflect on their learning process.

Similar to U.S., DBL in Australia is started from the educational problem of science and mathematics education (Norton, 2006). Relatively low participation in the hard sciences (mathematics and science) has become a concern with respect to the capacity of Australia to meet critical infrastructure projects. The problem is underlined by its roots in poor student attitudes towards and perceptions about the study of prerequisite subjects including mathematics and science. With this in mind, technological design activity was used to integrate the study mathematics so students could produce and explain a useful artifact. In other word, the technological design was employed into the learning of the mathematical and scientific concept that students were difficult to understand for a methodology of effective integrative strategies.

Due to unfamiliarity with design approach, K-12 science education particularly emphasizes how design differs from traditional inquiry approaches to teaching science. Design-based science is science pedagogy in which new scientific knowledge and problem solving skills are constructed in the design context (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Maaman, 2005). To construct and transfer new science knowledge and problem solving skills, design-based science supports student's solution of a new design problem in a real-world setting. The DBS design problems are focused on helping students construct new scientific understanding and practical problem solving skills through the design of artifacts. These artifacts are not meant to be a culminating experience where the student attempts to apply scientific knowledge that was learned in a traditional manner throughout a unit or course. DBS learning activities follow a design process that is very similar to the technological design loop. The results of the study found that knowledge was constructed during the enactment of the DBS activity and then was successfully transferred and applied in the solution of the transfer task. The transfer task was a real world scenario where the students had to design a kite that would fly a mile high. Traditionally, science education has focused on strong cognitive skills, for example, hypothesis generation, experimental design, and hypothesis revision. However, current research takes the dynamic design process with huge interests on building, testing, and evaluating models of phenomena. With this in mind, many science education programs have the same context as this trend.

On the other hand, other name employing design method in the field of science education was "*Learning by Design* (LBD)". Kolodner (2002) proposed a "LBD" approach by which science educators use the design process of technology education. Her process contains two learning cycles such as a "design/redesign" cycle and "investigate and explore". The story of the design in the context of Learning by Design had a strong background. Kolodner *et al.* (2003) attempted to blend "Problem Based Learning" and "Case Based Reasoning" in the middle school science classroom to implement the LBD.

Ⅴ. Key Benefits of the Design Methodology

All the studies investigating the integration of the STEM subjects were started with their own purposes. Key beneficial aims that the prior studies have pursued were (1) to improve academic achievement in their targeted areas, (2) to promote students' affective gains including their increased motivation toward academic subjects (e.g. science, mathematics, technology education, etc), (3) to facilitate collaborative learning, and (4) to explore STEM related careers and jobs.

1. Increased Academic Achievement

Design methodology or pedagogy was employed to facilitate students' academic achievement in each school subject. Apedoe, Reynolds, Ellefson, and Schunn (2008) aimed to promote students' chemistry knowledge through Design Based Learning. They designed a chemistry course using a combination of scientific and engineering design and included a variety of scientific knowledge such as atomic interactions, energy. Finally, they found that there was an increased achievement in their students' chemistry knowledge. Kolodner et al., (2003) used a project-based inquiry approach to science learning with two concentrations of the Case-Based Learning and Problem Based Learning. They also found a clear gain regarding content knowledge in the targeted domain. Bisogno and JeanPierre (2008) utilized a computer-based bridge building project to facilitate several concepts such as Newtons' three laws of motion and mathematical principles. Fitzerald (2004) included a variety of concepts (graphic design, basic drawing, sketching, mathematical measurement, oral/written report) in the context of the technological design. The efforts to integrate STEM areas have produced a fruitful outcome in terms of students' academic achievement and purposed to promote their students' increased knowledge related to STEM areas.

2. Promotion in Students' Affective Area

During the past decade, students' interest in design activities as a means to improve science learning has been increased (Minogue & Guentensberger, 2006; Puntambeckar & Kolodner, 2005). Simply these efforts were originated from the negative status like low motivation and attitude toward STEM areas. These design challenges provided a motivation with students in the context of the STEM education. Many researchers of science education investigated to verify increased interest, positive attitude, and promoted motivation toward STEM areas (Rowell, Gustafson, & Guilbert, 1999; Wender, 2004). McGinnis, McDuffe, and Gradber (2006) emphasized a rationale to integrate science and mathematics and stressed that hands-on activities have promoted the students motivation for learning mathematical concepts. Also, many studies using design challenge or design competition aimed to promote more active students' participation (De Romero, Slater, &

DeCristofano, 2006; Mingue & Guentensberger, 2006; Pilskow, 2008).

Employing engineering design projects in K-12 settings can promote students' interest toward STEM areas. Based on a synthesis of the previous research findings, we can picture the positive effects in the areas of students' motivation, self-direction, and even teachers' attitude through design methods that integrate STEM disciplines.

3. Collaborative Skill

In a design activity, students should begin to develop the ability to work in a team. Most of the studies using technological/engineering design have used "design team" for accomplishing the challenge or problem solving (Fitzgerald, 2004; Frazier & Sterling, 2008; Hutchinson, 2002; Pilskow, 2008). Venville, Rennie, and Wallace (2004) stressed the group skills and creativity as a benefit of employing technological design or design activity. Also, Mingue and Guentensberger (2006) emphasized the small group work during the design process and Hutchinson (2002) indicated a clear positive gain on the small group collaboration. Based on the empirical data (Kolodner *et al.*, 2003), students who have experienced design process consistently perform significantly better than non experienced groups with respect to collaboration skills.

Finally, design methodology to integrate STEM areas can help improve students' cooperation, collaborative work, level of responsibility in students' work, and appropriate communication.

4. STEM Careers

Design methods provided a means for students to function as STEM experts as they work toward solving a specific real-world problem situation through technological/engineering design. Apedoe, Reynolds, Ellefson, and Schunn (2008) found that students' interest toward STEM related careers had been increased through a variety of design activities. Infusing technological/engineering design in K-12 classrooms can promote students' interest toward STEM areas and attract diverse students to STEM related careers. Kolodner et al. (2003) emphasized that design methods introduced students to the real STEM careers.

Ⅵ. Summary, Implication & Conclusion

Design has been as fundamental to technology education while inquiry has been to science education. In spite of strong distinctions of two different disciplines, more recently, science education and technology education are pursuing the effective implementation of the design. In the context of the STEM education, the engineering /technological design has been a powerful tool to integrate STEM areas. The types of these efforts are "Technological Design", "Engineering Design", "Learning by design", and etc. Literature shows that collaborative work is necessary and imperative. However, educational communities in the field of STEM education still look for a bridge to integrate two disciplines.

The research findings of the 33 studies related to integration among STEM subjects suggest that technological/engineering design should be an effective strategic methodology or pedagogy. Even though the types or names used in each study were diverse, the key feature has reflected the benefits of design methodology or pedagogy. The names employed in 33 identified studies were technological/engineering design (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Bers & Portsmore, 2005; Cajas, 2001; Cunningham, Knight, Carlsen, & Kelly, 2007; De Romero, Slater, & DeCristofano, 2006; Fitzerald, 2004; Frazier & Sterling, 2008; Merrill, 2001; Minogue & Guentensberger, 2006; Norton, 2008; Venville, Rennie, & Wallace, 2004), Design Based Learning (DBL) (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005), Learning By Design (LBD) (Kolodner, 2002;

Kolodner *et al.*, 2003), design and inquiry (Lewis, 2006), scientific inquiry (Hatch & Smith, 2004; Parkinson, 2007; Perrenet & Adan, 2002), and so on.

We can summarize key benefits using design methods for integrating STEM areas. First of all, many research findings related to design methods are initially started from the current problems in the classroom. In science education and mathematics education, many students are frustrated with understanding abstract scientific concepts and having mathematics class organized by abstract and unattractive mathematical principles. In these strategies of rote practice, the science and mathematics class don't attract the student's attentions. In other words, the empirical studies using technological/engineering design have found their students' increased academic achievements. Also, compared to the science and mathematics education, technology education doesn't have much attention from the public. Within this context, design methods would be a special bridge to connect each discipline of STEM. The problems or situations (challenges or scenarios) in technological/engineering design are strongly associated with real world problems. STEM education is focused on emphasizing and applying the intersections and confluences among the four disciplines to practical applications within the real world. These approaches motivate students' attitude or interest toward STEM subjects. Third, the real world includes both the events and interactions of students in their everyday lives as well as the workforce that they will enter once they complete their education. Teamwork through frequent cooperative projects or learning provides a beneficial value to the students' future careers.

Considering the findings and conclusions, we can recommend several issues. The communities of STEM education should concentrate on the professional developments. Especially, the teacher's education programs related to STEM subjects should develop several courses emphasizing the application of a variety of design methods. In each discipline of science, technology, engineering, and mathematics education, they have to possess the open-minded attitudes toward collaborative works among STEM disciplines. Moreover, diverse strategies to promote the benefits using design methods for integrating STEM areas should be developed and implemented.

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Abstract

This study aims to investigate the key common topics identified and discussed in relevant literature associated with the integrative efforts among STEM disciplines. The key methodology and pedagogy were examined and the significant benefits of using the design method for STEM education were discussed. Meta-analysis was employed and qualitative approach was mainly used to synthesize the major findings and conclusions of the 33 empirical studies. The findings of this meta-analysis revealed that the types and names describing the design methods used the various terms, but the key features have reflected the similar pedagogical benefits and key characteristics. The engineering design is an effective strategic methodology and pedagogy for STEM education. In addition, the design methods show the key benefits including (1) to improve academic achievement, (2) to promote students' affective gains, (3) to facilitate collaborative learning, and (4) to explore STEM related careers and jobs. The collaborative works among STEM professions are needed to promote the benefits of using design methods for integrating STEM subjects.

Keywords: Engineering Design, Technology Education, Science Education, STEM Education