Design Thinking in STEM Education: A Review

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Abstract

Design thinking plays an important role in grooming creative and innovative ideas. Design and design thinking are attributed as vital traits in STEM education. Design ability is important in shaping students’ mindsets for future challenges and advancements in technology. STEM education will strengthen learning and will help to foster creativity, critical thinking, design thinking ability, problem solving and innovative skills. In this research, we try to focus on different factors and theories regarding design thinking and role of STEM education in inducing design thinking and innovative ideas. Design is not confined to just few academic and professional subjects. Design thinking ability helps in about each and every discipline of life. In this review, different research studies and their findings regarding importance of design thinking in STEM education have been explained.

Keywords: design thinking, STEM education, engineering, education

1. Introduction

Design thinking is not an individual task rather it is based on multiple factors. Normally design is referred to a few professional and engineering branches such as architecture, technology, engineering, fashion etc. All of these professional branches are based on vast experience, years of trainings and useful practices. These designing trainings and practices lead to beneficial end products. Most of the school subjects like science and mathematics are not viewed as designing subjects rather designing is more associated with subjects like art and vocational trainings. Traditionally, it is believed that methods and mechanisms of science and mathematics are vital to acquire skills and knowledge (Banilower et al., 2013). Unfortunately, little or no attention is given to design thinking and activities in most of the traditional school systems. Design activities help to create new procedures, structures and mechanisms which are mostly associated with professionals, not students. For engineering and technology-based fields, designing is a key and the most important activity (Dasgupta, 2019; De Vries, 2018). It is important to learn designing and design mindset in these fields. Therefore, inclusion of technology and engineering based subjects in school education develops new and untapped prospects of what a student must be learning. Design activities and development of design-based mindset can benefit students in number of ways (National Research, 2009). Design thinking certainly nurtures existing traits such as problem solving and crisis management in students and helps in induction and development of new ingenious, creative and innovative skills. The eminence of design thinking has been endorsed by school education systems due to recent developments emphasizing the importance of STEM education (Bybee, 2014).

Traditionally, more importance is given to science and mathematics in existing education system as identified by the International Association for Evaluation of Educational Achievements (IEA). In fact, Science and mathematics are major subjects in K-12 education movement. It is believed in some educational circles that science and mathematics are not the proper subjects to induce design and design thinking abilities in students. Therefore, responsibility for such skills are left for engineering and technology subjects. Such beliefs are needed to be altered. While it is expected that inclusion of technology and engineering in K-12 education along with integration of science and mathematics will bring different new skills for students. These new skills will definitely include design and design thinking abilities due to successful merger of science, technology, engineering and mathematics (STEM) education. STEM education has been widely advocated to prepare students for technological challenges and to cope with rapid technological advancements in almost every field of life. The aim is to train students for the future challenges through induction of new skill sets through STEM education (Li et al., 2019; MacIsaac, 2019). Basic school level education is an important milestone for children which are open to numerous ideas with huge potential. STEM education has what it takes to nurture these fresh minds for the diversity and technological advancements in modern era. Nurturing and encouraging children through STEM education will help them to actively take part in shaping the future technologies and overcoming future challenges. For the successful integration of STEM education, teachers must have all essential tools which will assist children in development of useful skills to bolster learning abilities. Incorporation of STEM education in curriculum, cultural activities, teaching techniques and daily routine of school is essential to impart all these useful skills (Kennedy & Odell, 2014).

Design thinking is not only limited to academia and professional fields, it can be helpful in different aspects of life. We all incorporate design thinking in our routine life whether it is traveling plan, styling, fashion, house decoration. And in academia, for research designing, experimentation, designing curriculum, instructional manuals etc. Designing also means to pinpoint the issue and to design solution through problem solving skills. Experts say that children have natural ability and eagerness to design, make things and then tearing them apart to see how things work. Which leads to believe that everyone is creative, and everyone can design and engineer things at basic level (Cunningham, 2009; Cunningham & Lachapelle, 2014). Therefore, it is important to pay close attention to kid's design ability and ideas to aid and stimulate their creative ideas and design thinking. This will strengthen learning and help in fostering creativity, design thinking ability, critical thinking, problem solving and innovative skills (Cohen & Waite-Stupiansky, 2019). This review paper includes different studies and theories related to successful integration of STEM education for induction of design thinking in school disciplines and curriculum.

2. Design Thinking Models

Design thinking is not a new concept in various fields such as engineering. Various fields have different interpretation regarding the concept of design thinking (Dym, Agogino, Eris, Frey, & Leifer, 2005). For example, in business and management studies, design thinking is attributed to critical thinking and careful planning for creative and innovative ideas. In engineering, design is perceived as a routine matter. In educational sector, design related activities are believed to be a theoretical activity to have documentable results. Vague concepts for design and design thinking have led to add confusion and difficulties in path to operationalize this concept in curriculum and educational activities. Even these confusions created problems in the field of engineering (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Wrigley & Straker, 2017). In engineering studies, trends have changed from Simon's influenced engineering model (Simon, 2019) to project based learning and various technical courses (Dym & Brown, 2012). To evaluate and understand the concept of design thinking in engineering studies and various other field of study, various methods and approaches have been coined. These approaches include design process modeling (Dym & Brown, 2012), comparing different expert approaches (Ahmed, Wallace, & Blessing, 2003), pinpointing design thinking skills and planning tactics (Wendell, Wright, & Paugh, 2017), taking into consideration different cognitive skills and features (Sweller, van Merriënboer, & Paas, 2019), evaluating design team course of action and strategies (Hu, Du, Bryan-Kinns, & Guo, 2019). Previous research and studies for design thinking have provided us with detailed evaluation by focusing on multiple aspects. A study by Razzouk and Shute (2012) explained that experts in the field of design thinking exhibited increased efficiency due to experienced based knowledge and opting for solution-based thinking of underlying problem (Razzouk & Shute, 2012). Such valuable results help in development of design thinking expertise and guiding through various design thinking stages.

School education is different from professional studies like art, fashion, engineering, architecture, etc. as these professional studies impart a very specific skill set. Design thinking is identified as a vital shaping ability and learning tool (McFadden & Roehrig, 2019; Wrigley & Straker, 2017). Not only this, it also aids in selection of efficient framework for school education along with proper integration of STEM education (T. R. Kelley & Knowles, 2016). Design thinking is not only attributed to professional engineering and in designing of school education framework but also believed to be a generalized cognitive progression with creativity, experimental data, feedback data and redesigning, covering different fields of studies (Ahmed et al., 2003; Strimel, Kim, Grubbs, & Huffman, 2019).

In order to train students for design thinking, the concept is needed to be explored through various formal and informal educational and design activities. In the past, design thinking has been studied through different professional design course and practices. A study by Johansson, Sköldberg, Woodilla, and Çetinkaya (2013) termed this thinking process as 'designerly thinking'. They summed up all associated studies and theoretical explanations into five categories related to design and designerly thinking: initiation of scientific investigation, different reflexive practices, problem solving activities, pathway for reasoning of different aspects and meaning creation. They used the phrase "design thinking" for design practices beyond the professional means for people lacking background knowledge in the field of designing such as people working in management. Design thinking is therefore attributed as much simpler form of ‘designerly thinking’. This design thinking is practicable for the students and educational activities in schools (Johansson−Sköldberg, Woodilla, & Çetinkaya, 2013). To identify main features of design thinking for detailed studies, Razzouk and Shute (2012) defined the design thinking as analytic and creativity tool, giving liberty and opportunities to a person for different experimentations, creation of different models, feedback mechanism and redesigning. These insights give us valuable information regarding design thinking suppressing the boundaries and limitations set by various designing disciplines (Razzouk & Shute, 2012). Li et al. (2019) explained that design thinking is the effective way to develop thinking models and prototypes in educational activities which will contribute to prepare students for modern challenges and problems (Li et al., 2019).

Design thinking is fairly new concept for educational systems and its importance is gaining recognition all across the globe. Still there are many unanswered questions and challenges such as how to effectively understand student’s design thinking process and developments for designing curriculum more efficiently to help students in this thinking process (Wrigley & Straker, 2017). This is also an opportunity for research studies to gain detailed and in-depth knowledge for the factors contributing towards design thinking ability. Experimental studies can significantly contribute to understand various aspects of students’ design thinking capabilities and developments (Dasgupta, 2019).

3. STEM Education in Development of Design Thinking

How planning and design thinking can and must be instructed or utilized has been a significant issue in various technical and professional fields. Various models have been proposed and developed for various purposes such as ways to educate and effective evaluations (Kretzschmar, 2003; Wright & Wrigley, 2019). Wrigley and Straker (2017) proposed a detailed educational instructive plan and steppingstone for the investigation of what course content should be taught and how it should contribute for designing thinking process through evaluation and learning new strategies. They contributed effectively by gathering and evaluating 51 courses related design thinking in various fields of business, art, management, engineering, innovation, etc. from around 28 universities globally. Their work and through evaluation led them to suggest five pedagogical steps for progress in design thinking covering every stage from lower to high order of thinkability and skills, anticipated for various design thinkability stages. These stages related to design thinking are classified and termed as the foundation stage, product stage, business stage, and professional stage (Wrigley & Straker, 2017). Taking a step further, they even explained these five stages of design thinking with Bigg’s Structure of Observed Learning Outcome (SOLO) taxonomy (Biggs, 1996) which are comprehension of knowledge, application, detailed analysis, synthesis and final assessment. The model is proposed after detailed analysis of professional courses regarding design thinking process in these universities. The stages are specifically designed for various stages design thinking and to further enhance design thinkability.

4. Role of Engineering for Design Thinking in STEM Education

Studies have shown that during school education, students can learn design thinking and can refine their design thinking process through induction of STEM education. Now with the introduction of engineering subjects and courses in school curriculum enabled educational experts and researchers to have deep insight regarding effects of engineering in shaping design thinking of students. These engineering subjects can captivate students and further help them in learning and design thinking in STEM education (English & King, 2015; Kelly & Cunningham, 2019; McFadden & Roehrig, 2019). Kelly and Sung (2017) explained and investigated how are engineering subjects helping grade 5 students in learning science. Students were found to have spent more time in computational thinking in protocol sessions. Each student on average spent 34% of more time on computational thinking when presented with math embedded design problem. Pre and post sessions tests of students exhibited significant improvement in science related problems. Most of students were able to understand the concepts used in science problems but few struggled to apply the concept in similar new situations and problems. Results exhibited that students can learn problem solving and design decision skills through successful integration of engineering courses in STEM education. School teachers must be emphasized on using engineering design as a tool to improve thinking ability of students in science. Also, to use this knowledge of reasoning and problem solving beyond these designed tasks and situations (T. Kelley & Sung, 2017).

Kelly and Cunningham (2019) explained how engineering design thinking gives the useful tools to enhance common and collective sense making, reasoning with facts and proper evidence and learning. Inclusion of engineering subjects aid in leaning science concepts more effectively due to frequent use of science-based concepts in engineering problems. Different physical, symbolic and even discursive artifacts for learning are some of identifiable epistemic tools drawn from engineering curriculum. These epistemic tools helped in development of models and prototypes, tradeoff between limitations and criteria in engineering-based design problems and proper communication with the use of conventional verbal, written and various symbolic models. It was analyzed that these useful epistemic tools shape learning and design thinking of students. Importance of these epistemic tools was explained with comparison and connecting what these practices aim to accomplish in terms of knowledge learning through this process (Kelly & Cunningham, 2019). Moreover, importance of the epistemic tools institutionalized in engineering was brought to light to be used in school education. There is a potential to point out, investigate and compare more identifiable epistemic tools from various STEM disciplines. New epistemic tools will further enhance students learn ability and design thinking development. STEM education is not believed to have cultural neutrality and role of culture in design thinking process and in various epistemic practices cannot be ignored. Culture will further boost up the design thinking process and increase learning for STEM education due to diversified classroom environment (Early Childhood, 2017).

Few researchers rather than solely putting mind on the use of designing in engineering practices, aimed in development of useful generic design practices in teaching approach to help students to enhance learning in STEM and STEAM (including Art) education (Chen & Lo, 2019; English, 2019). English (2019) reported and explained a 4-year longitudinal research based on 4th grade class which included design thinking problem solving exercise and activity spanning across all four disciplines of STEM education. With the target to focus on a shoe designing task, students used initiatory problem data to further examine and analyze data regarding types of shoe, fabrics, various size range and foot lengths. Scientific knowledge through science curriculum was used to get more insight and related knowledge about material being used. Further information regarding shoe designing and manufacturing was gathered. Different groups of students were given tasks in shoe designing. The whole experiment and process resulted in illustrating a student ability to learn from basic research regarding any topic. And a student's ability to further use that knowledge as a beginner designer in initial designing, redesigning and final design selection (English, 2019). Above work, framework, process and education designing levels for design development process are well reported in research studies (Wrigley & Straker, 2017). Along with explaining design development stages and process, English also describe the level of awareness among students for learning STEM educational knowledge and how to use it when needed or required. Students were able to make decision based on knowledge and give corresponding explanations. Design activities reported in research studies are well structured and designed keeping in mind the specific goals and teaching support. To get positive results for design related activities in STEM education, teaching and instructional methods should be employed. More work is required to overcome certain mechanism and teaching limitations to better facilitate students in design thinking development process.

5. Design Thinking and Integrated STEM Education

Research studies have explained the importance and mutual benefits of design thinking and integrated STEM knowledge. Studies also explained a student's ability in learning and development of design thinking by successful integration of STEM curriculum design practices (English, 2019; Fan & Yu, 2017). Fan and Yu (2017) performed and executed an experimental study through comparison of learning outcomes in high school students' groups for engineering STEM education and technology education modules. With the careful control over course content and other important aspects, students' abilities were analyzed for the time period of 10 weeks. STEM engineering students were found to outperform students of technology education module in terms of conceptualized knowledge base, high order design thinking and project activities for engineering designs. More analyses and investigation revealed the main differences among application of design thinking practices in both modules (Fan & Yu, 2017). Following study also included and explained positive and practical effects of integrated STEM knowledge in high school education. English's study explained briefly the beneficial effects of integrated STEM education in curriculum and teaching. Fan and Yu took a step further by designing an engineering design experiment comparing education modules among various groups of students. Similar benefits in students to learn and develop design thinking were reported in the aforementioned study(English, 2019).

6. Design Thinking in Mathematics and Science

Design learning can not only be learnt through engineering and technical knowledge but also through subjects like mathematics and science which form the base for engineering practices. Design thinking is not a new term in educational sector (Burkhardt & Schoenfeld, 2003; Cobb et al., 2003). Students should be emphasized and engaged in design thinking process, generation of idea and critical thinking rather than just presenting with facts and already known procedures. Mathematics is perceived as different and non-experimental course in comparison with other STEM subjects (English, 2019). Views, instructional methods and learning processes are needed to be altered in case of mathematics. These changes can be made through the application of project-based learning (PBL) in STEM education to be used in mathematics as well. Various research studies can be seen focusing entirely on mathematics elementary teaching with detailed analysis through investigations, various projects and activities. Orona, Carter, and Kindall (2017) investigated and explained how standard measuring units can be integrated in design thinking related activities. The study focused on multiphase engineering design problem and applying it to problem solving activities for 2nd grade mathematics. Students were engaged in question answering, brainstorming sessions, improving, learning and sharing. Students were asked to make relationship with hand measurement and different body and face features. The process efficiently integrated engineering designing practices and with standard measuring units (Orona, Carter, & Kindall, 2017).

7. Conclusion

From all above findings, it has been clear that design thinking must not confined to few limited professional or academic fields. The importance of design thinking and role of STEM in nurturing it cannot be denied. Introducing school children to science and technology fields help them in design thinking ability and design ideas. School education system must change the ways of learning and teaching science and mathematics in accordance with design thinking prospects. It has been found through numerous studies how STEM education can provide all useful tools and opportunities to students in learning design thinking ability to face future technological challenges and rapid advancements. STEM education can further provide students with number of opportunities in diverse environment covering all professional disciplines. STEM education employs professional design ideas to nurture and prepare young minds for future innovations. Design thinking certainly nurtures existing traits such as problem solving and crisis management in students and helps in induction and development of new ingenious, creative and innovative skills.

This review paper explains design thinking with different models through number of studies for school education. Although, the studies are mostly limited to professional disciplines and engineering, but now design thinking is gaining its due recognition in school education and in shaping young minds. Design thinking along integration of STEM education, has ability to provide sound foundation for development of new structures and models in current education system. Implementation of STEM education through prospective of design thinking has been discussed in detail in this review paper. It has been acknowledged that educational institutions have started to accept the importance of design thinking and STEM education. However, more work is required to overcome certain mechanism and teaching limitations to better assist students in design thinking development process.

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