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AN OUTLINE OF WORLDWIDE BARRIERS IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) EDUCATION

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ABSTRACT

This study aimed to identify and classify the barriers in Science, Technology, Engineering, and Mathematics (STEM) Education around the world. The barriers have been investigated in the intrinsic, extrinsic, and institutional domains by reviewing the literature and related works. In STEM education, the intrinsic barrier focuses on the personality of teacher and student; and extrinsic barrier mainly results from the inadequate and or inappropriate arrangement of infrastructure. Meanwhile, the institutional barrier is specific to curriculum, policy, technology, as well as organizational sustenance in the education field. From the twelve of sixty previous studies in data resources, the obtained percentage of barriers are 38% for intrinsic, 33% for institutional, and 29% for extrinsic, respectively. It has been revealed that these domains have quite a similar percentage, but intrinsic factors came up as the most reliable barrier in STEM education.

Keywords: barrier, STEM education, intrinsic, extrinsic, institutional

INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) Education is known as a multidisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons in contexts that make connections among school, community, work and the global enterprise (Akaygun & Aslan-Tukak, 2016; Cevik & Ozgunay, 2018; Tsupros et al., 2009). STEM subject learning provides benefits for students. It gives opportunities to the students to integrate multidisciplinary research topics in their studies, too (Honey et al., 2014; Jacobs & Eccles, 2000). Further, it also comes up as a key to achieve critical competencies and also as the unfold learning, which is an object created by a human being during learning process, that supports students` explorations, questions, conversations and reveals how competent the students are in science, technology, engineering, and mathematics subject (DeCoito et al., 2016).

The critical competencies are divided into five domains: problem-solving skills; social communication skills; technology and engineering skills; system skills; time, resource, and knowledge management skills (Jang, 2016). Moreover, STEM education is also believed to be able to contribute to the development of 21st-century skills (Altan et al., 2018). Such an approach is

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based on the competencies that should be achieved for each school or curriculum.

Furthermore, STEM Education has been applied to the elementary to higher education field for decades in the USA and many Asian countries recently, including Indonesia (Hwang & Taylor, 2016; White, 2014; Mutakinati et al., 2018; Radloff & Guzey, 2016). It has become more prominent for the researchers, the government, and educators because most of the findings from previous researchers show the improvement of students' achievement through STEM implementation (Afriana et al., 2016).

STEM is also believed to be a subject required to solve the global challenges in the world (Shernoff et al., 2017; Tanembaum et al., 2016). Currently, global challenges such as climate change, ecological scarcity, and emerging and re-emerging infectious diseases clearly have connections to the STEM discipline which subsequently supports the politics and national security (Bybee, 2013; Caprile et al., 2015; National Research Council, 2011, 2014; Freeman et al., 2014; Scientist, 2013; Society, 2014). As a part of these challenges, it also shows that the STEM skills as the results of STEM education are vigorous to each sector of international economics growth (Reider et al., 2016). Hence, STEM Education has a significant impact on real life around the world.

The existence of STEM Education itself cannot be separated from the needs (Lynch et al., 2015). In order to achieve the desired outcomes, The President Council of Advisors on Science and Technology (PCAST) is now preparing strategies such as supporting around 100,000 newly STEM educators by the year of 2020 in the USA through professional development program (Radloff & Guzey, 2016) which has also been followed by other countries as a starting point for STEM education.

However, the existence of the barriers has been reported discretely with undefined category and become a difficulty for the government as well as researchers to conduct well-implemented STEM Education (Connors-Kellgren et al., 2016; Geng et al., 2018). Hence, the barriers have been identified from many points of view such as educators, students, government, community, family, institution and so on (Asunda & Walker, 2018; Castleman et al., 2014; Kennedy & Odell, 2014; McDonald, 2016).

Furthermore, we classify the barrier into three domains (intrinsic, extrinsic, and institutional); based on a dominant category from the literature that focuses on a secondary level of education. This will be the first study that discusses the barrier in STEM education around the world in a specific grade. It is expected that the results could provide insightful findings for the researchers, government, and educators on how STEM education should be implemented. In the end, the following questions were addressed: (1) What are the barriers? and (2) Which domains and what barriers influence STEM education more? In this report, the results of the literature review for the common barriers in STEM education will be presented, and the characteristics of the barriers will be discussed.

METHODS

We have carried out a literature review for the barriers in STEM education that gathered all available current literature. The literature were selected from the following online journals: J*ournal of Educational Research*, *International Journal of Science Education*, *International Journal of Science Education and Mathematic*s, *Journal of Science Education and Technology*, *International Journal of STEM Education*, *American Journal of Applied Psychology* as well as several books. In the selected literature, the STEM barrier studies have been conducted between 2005 and 2017 in the USA, Israel, and Spain. By combining the review results, the barriers to the implementation of STEM education were identified — the barrier defined as an aspect that obstructs one's capability to improve. Its` probability comes from the situational, physical, cultural, or individual states (Shadle et al., 2017).

In this research, we have categorized the barriers into three domains: intrinsic, extrinsic, and institutional. The keywords used in searching these data sources were: "STEM," "Education," "educator," "high school," "barrier," "challenges inhibitor," "factor." At the initial search, sixty articles were selected; we tried to narrow down to twelve by use of the most specific keywords, and finally, these articles were used to the literature review as a data source. The review results derived from twelve kinds of literature focus on the barriers of STEM Education at any level. One of them was carried out using qualitative and quantitative methods (Scott & Martin, 2013), the eight of them adopted only qualitative approach such as interview and review (Ejiwale, 2013; Henderson & Dancy, 2011; Henley & Roberts, 2016; Nadelson & Seifert, 2017; Shadle et al., 2017; Shernoff et al., 2017). Three of the studies used quantitative method (Chachashvili-Bolotin et al. 2016; Coppola et al., 2015; Ilumoka, 2012).

RESULTS AND DISCUSSION

The old curriculum structures that have been settled for years were found to become barriers in the implementation of Interdisciplinary STEM education. Even though the outcome of STEM Education is promising, educators still find it to be hard to run the new system. Furthermore, the barrier then extends to other aspects as well. We listed them in the three broad categories based on the pre-existing codes utilizing the tendency of those barriers and formatted in a table (see appendix).

Each barrier was defined as follows; (1) intrinsic barrier that is related to personnel of the teacher, for example quality of teaching, educator's personal experience and awareness, attitudes, beliefs, practice or preparation, and resistance; (2) extrinsic barrier which is resulted from inadequate and/or inappropriate configuration of infrastructure for teacher such as gender, racial, time, access, support, resource, training for educator, cultural; and (3) institutional barrier, that is specific to curriculum, policy, technology, as well as organizational sustenance in the education field (Maguire, 2008; Shadle et al., 2017).

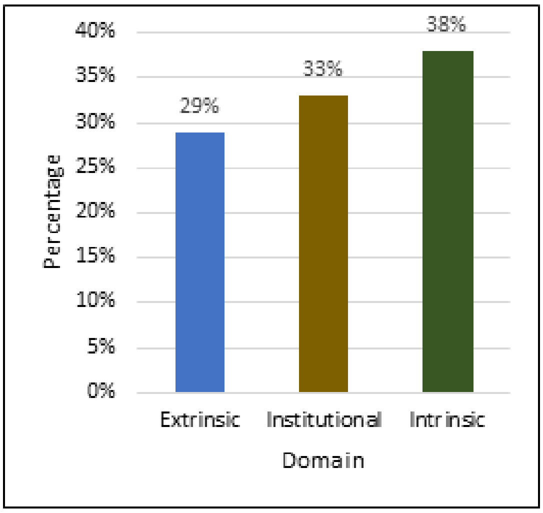

Figure 1. The Percentage of Each Domain in STEM Education

The amount of the three barriers is shown in Figure 1. The barrier indicates the challenge before and during STEM education implementation for a secondary level around the world with 38% of the intrinsic domain as the highest percentage. It consists of 13 barriers between teachers and students, followed by 33% of institutional consisting of 11 barriers that talk about the school curriculum, and 29% of extrinsic barrier covering 10 items that mostly speak about family, culture and social support.

Intrinsic Barriers

In the present study, 13 barriers were identified as intrinsic barriers. Most of them focused on education of the educators, time management, and educators' ability to understanding the content of STEM education as well as pedagogical knowledge. We found that educators do not have enough time to prepare the lesson, especially for the educators who have a part-time job or other activities outside the school. STEM education requires a deeper understanding of each subject compared to regular education. Since the existence of educators are vital in this system, it is necessary for them to put more efforts and commitment on STEM education in order to maximize the output of this system (Chachashvili-Bolotin et al., 2016; Coppola et al., 2015; Ejiwale, 2013; Nadelson & Seifert, 2017; Shadle et al., 2017; Shernoff et al., 2017). Hence, it is essential to consider the higher education level of educators or provide STEM professional development program.

On the other hand, students seem to struggle to be involved in STEM education. This type of education demands higher knowledge, which makes students are not ready to face this system. Coppola et al. (2015) suggested that this type of barrier might exist because the levels of STEM Education competency and student capability are not balanced. As a result, the students could not keep up with the requirement of this education yet; therefore, it needs more time and more effort to fix both.

Extrinsic Barriers

Some studies have revealed that the structure of the time management system in schools can become the main problem in STEM education. Educators do not have much time in the class for the learning process (Shadle et al., 2017). It is not a surprising thing that the time management of institution indirectly influences class development; consequently, the process of implementation in STEM Education is affected. Furthermore, STEM education was considered to be inappropriate for the old curriculum due to the lack of resources related to materials and tools (Ejiwale, 2013; Henderson & Dancy, 2011). It seems that more efforts are required by the teacher and all of the actors in the education field. However, some educators remain to employ traditional teaching materials very often (Coppola et al., 2015). This point is related to the intrinsic and institutional barriers when educators do not have enough education skills as well as teaching interests. As we know, it can only be a starting point for them to find and understand STEM Education.

Students can be influenced by their family and the social environment. If their family is familiar to STEM education, or they have friends or colleagues who also studied in the STEM Education field, the students may be interested in STEM education (Chachashvili-Bolotin et al., 2016; Henley & Roberts, 2016). Family support may indirectly create the imbalance of gender in the STEM field. Commonly, parents tend to make male children have competitive motivation in STEM-related subjects, whereas they tend to believe that girls should have higher language and reading competences. Moreover, young males are more likely to receive support from their parents to develop mathematics and science-related activities than young females (Eccles, 2014; Jacobs & Eccles, 2000). In addition, Sainz & Muller (2018) also indicated that the birthplace, as well as the educational level of the mother, might influence the choice of the course in the future study.

Institutional Barriers

The institutional barrier has been talked more about the program and organization in the STEM education field. The problems that we found from previous studies were related to the classroom size, which was too big. Therefore, it was significantly challenging to conduct a one-on-one interaction between educators and students; eventually, it will affect the creativity of cooperative learning (Henderson & Dancy, 2011). Besides, uncertain goals, school structures, and the unfitted curriculum become significant challenges to be solved as they are connected and influenced each other in the implementation of STEM education (Coppola et al., 2015; Henley & Roberts, 2016).

In one school, all of the participants, such as educators, students, supervisors, as well as administrators, are considered to become potential barriers. Each of them should have enough understanding of STEM education to cultivate rich STEM learning experiences and expertise in their schools. Hence, we can see how STEM education, at some point, has to be explored. The government should take one big step to socialize the importance of STEM career in the future as well as to improve the infrastructure to support STEM Education to be more attractive for educators and students. This is parallel with Shadle et al. (2017), who elucidated that one of the barriers in STEM Education is culture. As widely known, every country, province, even school has a different culture so that it is difficult to fix the problems created by the differences. Hence, there is a possibility that the culture can become the last barrier in the designing and the implementation of STEM Education (Shadle et al., 2017). The previous explanation describes that the intrinsic barrier becomes the central part of STEM Education. Nevertheless, it cannot work correctly without support from extrinsic and institution; the connection among educator-family-school will be a perfect combination during the implementation.

There is a limitation in this study in terms of the area where the research has been conducted. The most studies referenced in this research were held in the USA, and a few numbers of which were found in Israel and Spain. This information indicates that the environment or atmosphere for the barriers in STEM education might be different from those in other countries. Hence, further research is needed to be performed in other regions across the continent to get a better understanding of the implementation of STEM education. The results of this study can be considered as a starting point to measure and analyze the conventional barriers in STEM education. For further investigations, we are going to investigate the obstacles of STEM education in Indonesia as one of the developing countries which involve the analysis of the school curriculum as well as on the government curriculum for the STEM education.

CONCLUSION

The barriers to STEM education have been investigated using a literature review. We have found that the intrinsic barrier emerges stronger than the extrinsic and institutional barriers. The intrinsic barrier becomes the first intention for educator, institution, and government before and during the implementation of STEM education. Moreover, it revealed that these barriers had connected significantly. The STEM education can create more support for the quality of the education around the world; it can be used to support students` understanding, idea, skill, and other ability as well as their decision for the students' future career.

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APPENDIX

Table 1. Category of Barrier in STEM Education in Educator and Student Point of View.

No.	Barriers / Domain	Intr.	Ext.	Inst.
	Expectations of Content Coverage (much material to be understood and choose to skip)	*		
	Student resistance (poor student study skills, not prepared to think independently, resistance to change their understanding, unfortunate inspiration, Self-efficacy and lack of confidence as well as student interest)	*		
	Poor content preparation, delivery, and method of assessment, they are not familiar enough with the content	*		
	Lack of hands-on training for students	*		
	Inappropriate level for students so they found the difficulty	*		
	Does not fit in with standards/state testing. They need the effort to implement a very different structure in an educational system	*		
	Outcome expectations	*		
	Instructional challenges, Lack of pedagogical skills/information	*		
	Educator STEM knowledge and their professional mindset	*		
	Teacher`s education (need for course and workshop to face the real world problem solving through teamwork)	*		
	Lack of knowledge about how to effectively spread the use of currently available and tested research-based instructional ideas and strategies	*		
	Lack of instructor time (too busy with substantial teaching loads and research responsibilities, lack of time for collaborative planning with other instructors & Instructional time)	*		
	Insufficient assessment methods and processes	*		
	Little research effort devoted to the study and improvement of STEM change strategies or models, lack of research collaboration		*	
	Departmental Norms (traditional method as the norm and no local role models to offer supportive; Loss of autonomy:□ force faculty to teach and assess all the same way, less individual control of content and methods)		*	
	Time structure in the class (limited)		*	
	Gender and racial imbalances, especially in engineering		*	
	Poor preparation and shortage in supply of qualified STEM educators, Lack of investment in educators professional development		*	
	Students are pulled out for support		*	
	Family background and support (Everyone in the family was discouraging about going to STEM, No family members had previously attended college or work in STEM field)		*	
	Social support (Each region has different provided education, it makes student discourage to learn if the student is too tricky to find STEM education, or High schools do not offer classes needed for STEM fields necessary in college, such as calculus, or No motivation to pursue STEM careers in high school)		*	

	Lack of resources (materials and tools, poor condition of laboratory facilities and instructional media	*	
	The current culture is unsupportive	*	
	Class size and room layout (a Large number of students)		*
	Lack of support from the school system, Not enough support from administrators		*
	Does not fit in the curriculum		*
	Insufficient number of specialized classes were offered at the high school		*
	Conflicts with institutional rewards/priorities		*
	Departmental divisions		*
	The uncertainty of goals (on retention) and vague goals of the faculty		*
	Challenges in engagement across faculty rank		*
	Misalignment with accreditation requirements		*
	School structure and organization (school schedule and various goals of schooling must be reorganized)		*
	Pre-service education (various STEM disciplines exist in many institutions that delivering pre-service education)		*