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STEM (Science, Technology, Engineering and Mathematics) Education and Its Characteristics.

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ABSTRACT: *Presently, STEM (Science, Technology, Engineering and Mathematics) creates a great social impact by solving globally challenges. These subjects crossover and to promote the economic development, reduce the inequality gap and shape the current workforce. STEM have strong influence in economic characteristics, educational characteristics, government characteristics and social characteristics. However, this article focuses on the social characteristics with two main components which are fertility adolescence rate and unemployment rate.*

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I. INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) refers to an integrated group of academic disciplines concerned with scientific inquiry, technological development, engineering design, and mathematical reasoning.

Economic characteristics refer to an individual's or group's position within a social and economic hierarchy, commonly operationalized through indicators such as household income, parental occupation, and access to material resources.

Social characteristics encompass contextual and relational factors, including family background, cultural environment, and community structures that shape individual development and opportunities.

Educational characteristics refer to measurable attributes related to educational attainment and experience, including level of schooling completed, academic achievement, type of educational institution attended, and access to educational resources.

Besides, the study objects to find out the components of social characteristic of STEM and give some suggestions.

The study aims at finding out the answer for this research questions:

- What is STEM and STEM education
- What are the economic, educational, government and social characteristics of STEM?

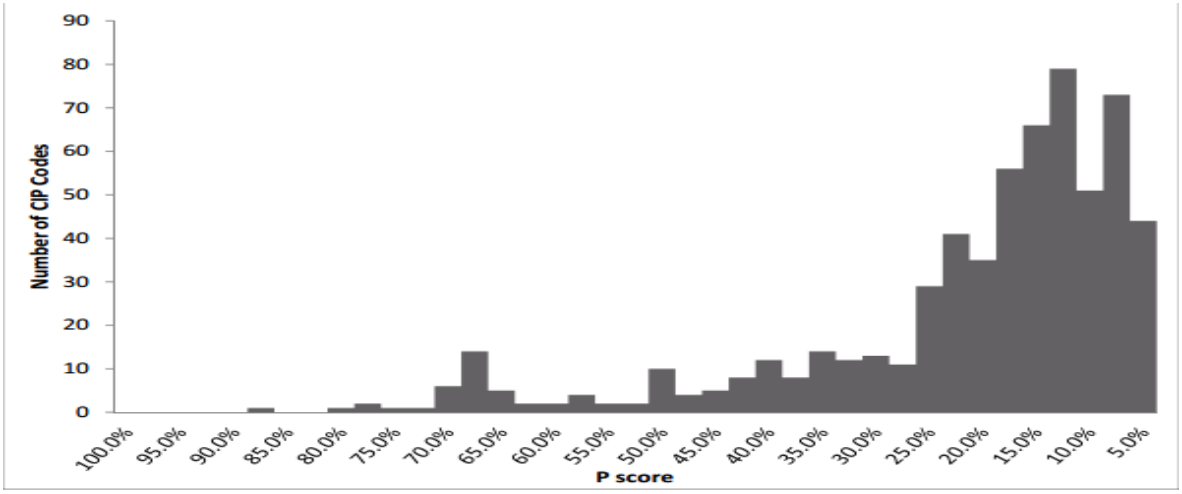
II. LITERATURE REVIEW

1. Overview of STEM and STEM education

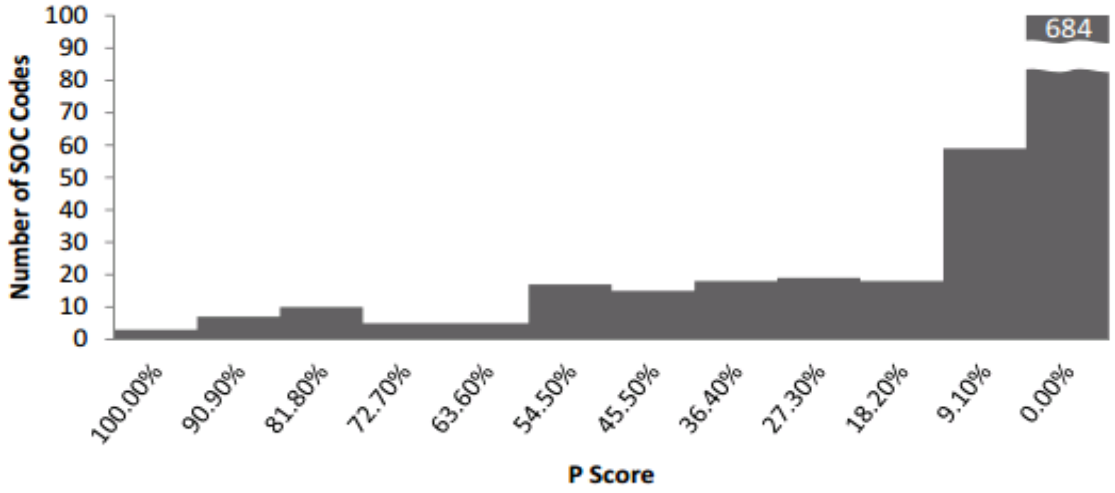
1.1 What is STEM?

Koonce et al (2011) mentioned Judith A.Ramaley as the one who coined the term of STEM which related to teaching math, science, engineering and technology. The importance of this field in economics development is soon recognized as Donovan et al, (2014) reconfirmed the significant contribution of technology and science as well as math in GDP growth. Hanushek et al, (2008) had predicted that if America had improved its PISA score by 50 points in 1990s, from 2015 and afterward, American would have experienced a strong economic growth which is enough to cover national education expense. However, clear definition of this term and its classification is far beyond reality. Koonce et al, (2011) try to address this question by analyze this term in two distinct views-educational (CIP) and occupational (SOC). The frequency a discipline shows up in total number of definition is used for research. Koon et al, (2011) proposed that STEM could be classified into 3 classes using CIP. High-frequency STEM includes all the STEM subject with the present at least 60% in all definitions. Medium-frequency STEM is less than 55% but greater than 25 % while low-frequency STEM is lower or equal to 25 %. Different criteria are applied under using SOC. The result are summarized in the following table:

	Using CIP	Using SOC
High-frequency	≥ 60 %	63.6%≤ X≤100%
Medium-frequency	25% ≤ X≤55%	18.2%≤X≤54.5%
Low-frequency	≤ 25%	≤9.1%



Source: Adopted from Kooonce et at, (2011)



Source: Adopted from Koonce et al, (2011)

The first version of STEM acronym is SMET which is proposed by American National Science Foundation, cited by Sander, (2008). After the adaptation, the term has been commonly known among educators; nevertheless, it seems like this term only stands for 4 distinct and distinguished majors while its application which has much more to deal with. William, (2011) claimed that while STEM phenomenon was attracting a lot of attraction, he believed that there is no consensus among educators about what STEM is how each filed should be linked to each other. Furthermore, it appears to be that several disciplines and occupations which require STEM knowledge, are still under the heated debate on whether they are branches of STEM or not. For example, social science, biology and their possible job in the labor market such as scientist, manager or educator. According to American ESA (Economics and Statistics Administration), they accept managers but exclude educators and social scientists.

1.2 STEM education.

Sander, (2008) claimed that the role of STEM education should be interacting and connecting between 4 different majors. However, the difficulty is far more than expectation and it requires a joint effort to move beyond the slogan of STEM application, Bybee, (2010). Nevertheless, the advantages of STEM education cannot be ignored. William, (2011) in his research cited that investment in STEM will facilitate the development and innovation of America's technology in order to affirm and consolidate the position of America in global market, (Obama, 2009). The United Kingdom takes advantage of STEM education to cultivate the capital for development through the channel of enterprises and invention, (STEM program nd, 2010). Gonzalez & Kuenzi, (2012) mentioned the importance of scientific thinking which are cultivated by STEM education in national power and

competitive advantages. In US, policy makers place a critical importance on promoting STEM education to deal with newly emerged problems of 21st century. In order to complete those tasks, Bybee (2010) suggest that group work and lab research activities as well as project based learning should be incorporated into the teaching curriculum. Improving the competencies of a nation is not only the economic imperative of STEM education. Several researchers claimed that STEM education had not taken into consideration the cost of economic growth such as environmental degradation or damaged social well-being. But this effect is not consistency because whether the economic development has no ecological damage or these damage could be remedied by advanced economic. In the latter case, it better to raise the awareness of students and role of STEM education in finding the solutions for environmental degradation, Donovan et al, (2104).

One persisting problem in STEM education is the gender equality which really hinders the contribution of this field due to the fact that talented individuals are dissuaded because of non-related ability reasons. In general, Shannon et al, (2019) illustrated the issues according to the geographical distribution. It is clear that countries which are in the north and the south hemisphere have better gender equality. It seems like getting closer to the equator will lower the gender equality in STEM fields. For example, Canada's figure is 50 % higher than Mexico or northern African countries for woman contribution to STEM research. Ellis et al, (2016) found out that women tend to drop out of the course more likely than man. Su and Round, (2015) agree with this finding by reconfirming that women are found to be overwhelmed in social sciences but only scare in STEM fields. They mentioned the difference in interests among genders toward STEM subject matters in students' choice. The situation is described in the following figure.

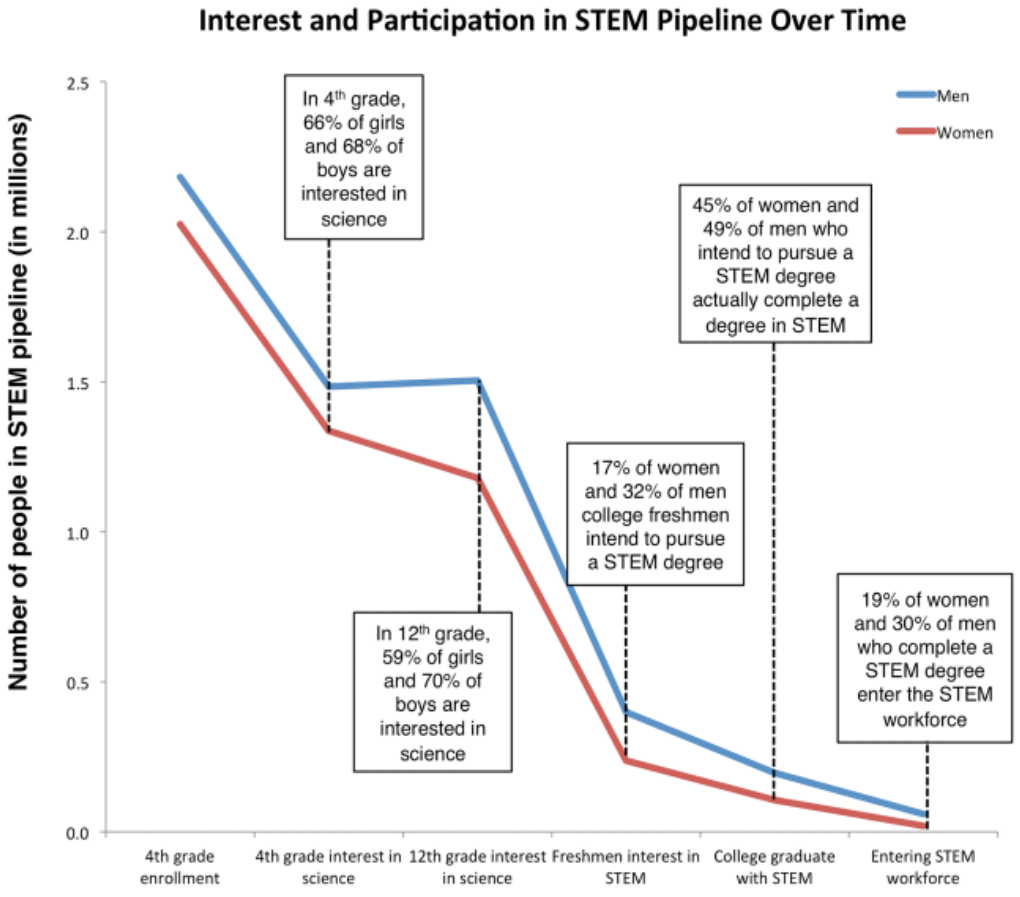
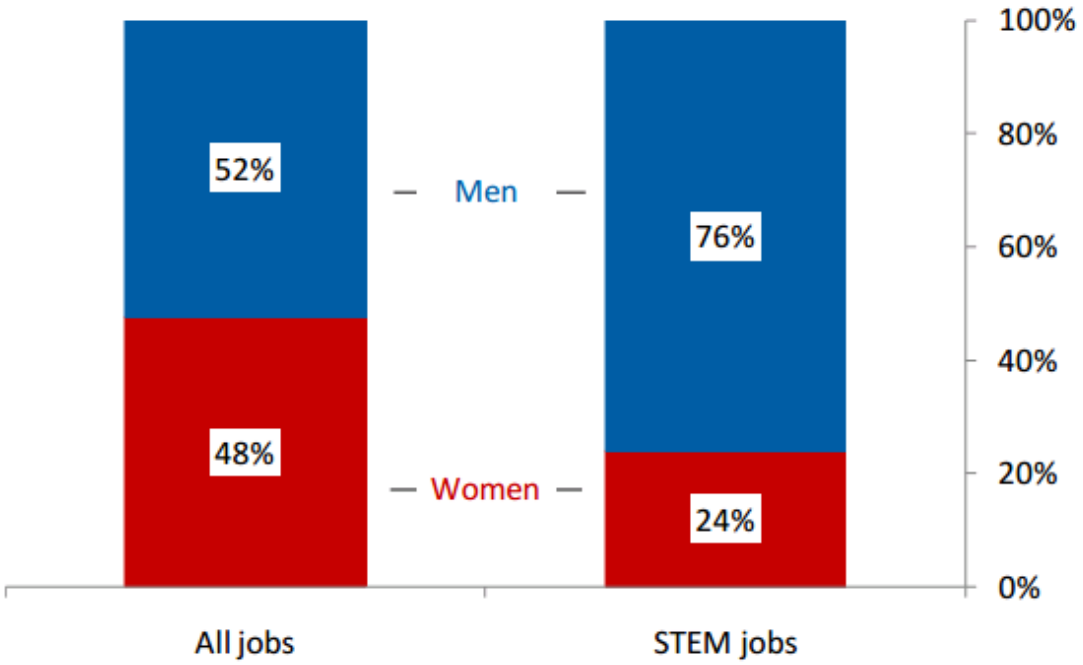


Fig 1. Participation of women in STEM.

Source. Adopted from Ellis et at, (2016).

In the labor market, the present of woman in STEM- related jobs are also minor, according to U.S Department of Commerce ESA. While women contribute for nearly a half of labor workforce in general, this figure is only a quarter in STEM jobs.

Figure 1. Gender Shares of Total and STEM Jobs, 2009



Source: Adopted from U.S Department of Commerce ESA. Note: The figures are calculated for people who are 16 and over.

2. STEM Participation and its inter-relationship with national characteristics

2.1 Economics characteristics:

Firstly, from the point of economics view, it has been proved that there is strong link between STEM with its component with economic growth. Osborne, (2000) claimed that teaching STEM is one of the most effective way to promote economics. Innovation is a driving force for any country which aims for higher growth rate, the result from this is higher demand for engineer scientist, Osborne, (2000). Hanushek et al, (2008) believe that education contributes to the development by nurturing the human capital, in particular, STEM education focuses on science and technology. He proposed using a combined result from two test, PISA and TIMSSA as a single variable to forecast the GDP growth. In more details, Hanushek & Woessmann, (2011) investigated and found that countries which achieved higher test scores in 1960 faced a higher growth rate afterward until 2000 compared to other countries with lower scores. Roschella et al, (2011) claimed that there is a widely recognized relationship between scientists and engineers are the one who lead the innovation needed for the national economic growth. Take Japan for an instance, Kitada & Harada, (2019) attribute the enormous success in economic recovery after war in Japan to the investment in STEM education.

GDP per capital and effects on STEM attendance

Gross domestic product is the full term for the acronym GDP. There are several definitions with different approaches to both its core and measurements. According to Hubbard and O'Brien (2008, p.215), it could be measured as the monetary value that comes from the total goods and services made by a nation on a yearly basis. Noticeably, they also mentioned the ignorance of intermediate goods to avoid the trap of *double counting.* Resell value is not also included in the calculation, (Hubbard and O'Brien, 2008, p.215).

Another way to measure the wealth of each individual is GDP per capital. This can be obtained by dividing the GDP by total population as the following formula:

$$GDP\ per\ capita = \frac{GDP}{Total\ populaiton}$$

However, despite the first impression of useful tools for economics analysis, these concepts has been criticized for several limits when it comes to well-being issues and process of any country. Bergh (2009) mentioned the fact of unsupportiveness of GDP for well-fare measurement. While it is true to claim the positive relationship between these two indicators, Bergh (2009) indicated that the coefficient should be nearly equal to zero. He used an example of 400 million times increase in GDP after 1000 years with the rate of 2 %, the same

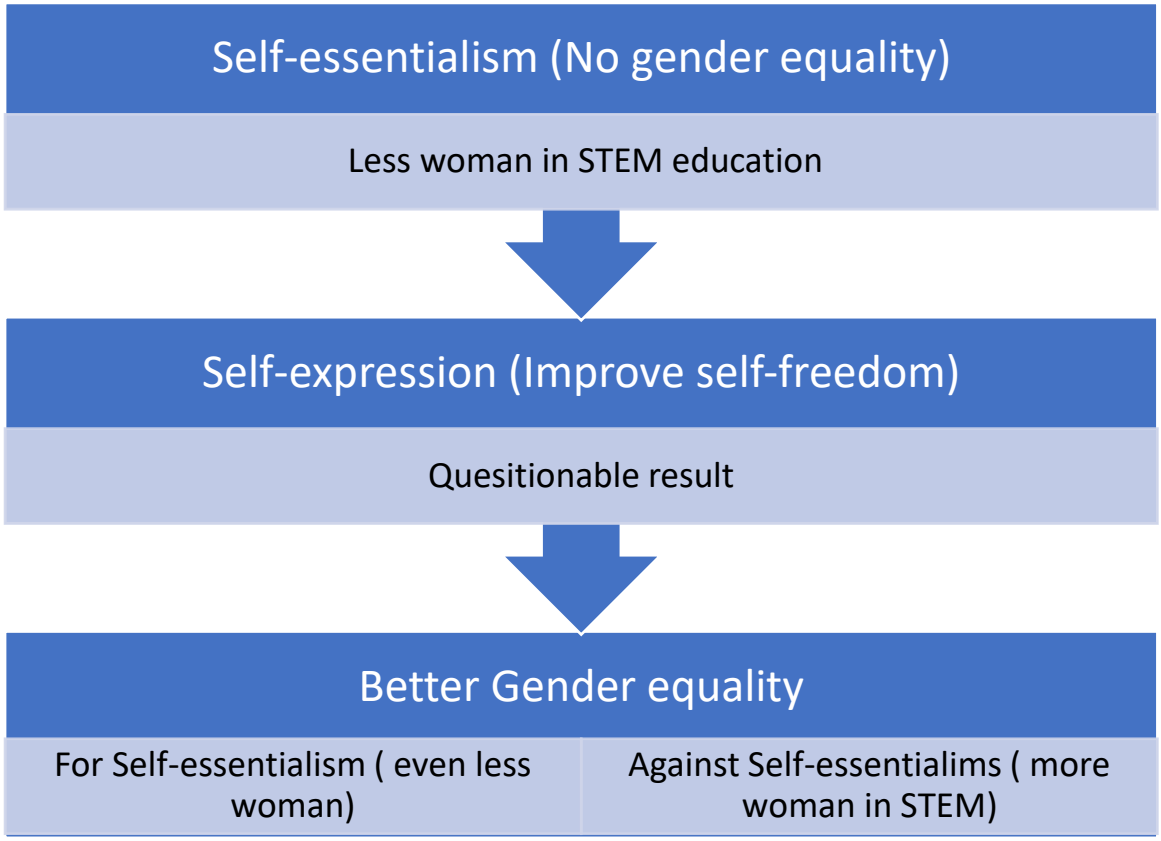
effect could not be expected in well-fare for citizens. Hubbard and O'Brien (2008, p.224) indicated the problem of equality versus efficiency which cannot be observed by using GDP alone. Moreover, pollution problems and it cost are not reflected by GDP figure. Bergh (2009) added the last point of how happiness should be measured in which he believed that GDP is not sufficient.

To have a closer look at how an individual makes decision, GDP per capital is used in this article and this is also a good indicator for predicting the STEM participation and the discrepancy between men and women in their educational choice. According to Van den Broek & Voeten, (2002) males are more sensitive to financial incentives than females which can strongly affect their education choice in general. For STEM education in particular, an inverse proportion is found between economic growth which can be seen by an increase in GDP or GDP per capita and science attendance for women. Charles and Bradley, (2009) even take this point further and pointed out that rather than enhance gender equality, economic growth or GDP would worsen the situation This means that as the country becomes richer, woman becomes freer to make their choice and in most cases, those are not STEM-related majors. For example, Finland faced the highest segmentation in education according to Charles & Bradley, (2019). In developed nations, women are more aware of their role and rights which in turn encourage them to avoid STEM curriculums. However, there are several researchers cast doubt on this finding. Riegle-Crumb, (2005, cited by Ayalon & Livneh, 2013) found that the effect of GDP on the woman's attendance in math courses cannot be proven. This result is also supported in studies carried out by Guiso et al (2008, cited by Ayalon & Livneh, 2013). Similarly, Baker & Jones, (1993) also attribute the higher level of equality to and an advanced economy. The situation has been confirm for conventional teaching methods; and even for online courses of which evidences are found by Jian et al, (2016). In their research, they cited that in the MOOC (Mass Open Online Courses), most of all learners are young and male from develop countries, of course, with higher GDP, (Chirstensen et al, 2013). After running the model, they concluded that for the case of online course, economic development is associated to the disparity of gender in STEM online course. They explain that because in developing countries, when the free course available free online, women have the chance to access to all the content which maybe not taught in their education system.

2.2 Gender Equality and STEM participation

Gender equality has been the focus of policy makers as well as educator in an effort to utilize all the potential labor workforce. However, gender inequality is a big problem on the way to make this dream come true because it prevents people to study and do the thing they are good at or even leads to gender inequality in several fields where the best are not present. O'Brien et al, (2019) just wonder how the answer to this issue is so difficult to be found. They hold a belief that the difficulty arises because of the complex nature of the problem as well as all the available definitions of equality are not adequate since equality improving is not a single dimension approach but the interaction between different contexts including office, school or even at home and on personal level. Stoet & Geary, (2018) coined the term of *gender equality paradox* which describes the negative of effect of gender equality on STEM participation. Shannon et al, (2019) in their research confirmed this idea by pointing out that countries with larger gender equality often face the largest gap of inequality in STEM courses attendance. They proposed a hypothesis that both internal characteristics and social characteristics have influence on the decision to follow STEM program which later results in gender gap in STEM curricular. Since human beings are assumed to be rational, we all react to the incentives think of marginal benefit. By comparing strong academic points and social factors each individual can measure their benefit to follow or not. Charles& Bradley, (2009) used two ideas of gender-essentialism and self-expression (including gender self-expression) to explain why in more developed economy, the gender segregation is more serious. For the gender-essentialist, it is believed that men and women are born with different and fixed characteristic, innate quality and natural abilities of which the result would be specialization in different areas in studying and working. This idea dominated in the past when girls and boys were educated in different ways toward the same problems which caused the bias of job selection and subject selection in studying.

In order to promote gender equality on general and education in particular, western researchers promoted the idea of self-expression which was cited by Charles & Bradley, (2009). According to their research, self-expression including gendered self-expression which allows women feel more free to pursuit their dream and favorite activities regardless of social judgment and innate academic strengths. Of course, this phenomenon would result in two different results based on whether their personal preference is for or against the gender-essentialism. On the one hand, if woman have the right and are willing to express themselves as domestic supporter and chose to do auxiliary jobs, this means a traditional bias which later would widen the gap of gender in choosing job and subjects. This is illustrated by an example taken from Japan, Kitada and Hatada, (2019) cited the work of Akai, (1997) that even recently women in Japan still prioritize family over the work and education. Whereas, woman who chose to follow their ambitions without considering the biased role granted to them by self-essentialism, there is a chance to narrow the gender gap in STEM education. We summarize all the causes and results in the following diagram:



While the first consequence is very clear and has been mentioned by several researches above, the latter case of increasing number of woman present in STEM education are being under investigation. There are several evidences to claim that, woman are overrepresented in several fields of STEM. Su & Rounds, (2015) mentioned the rise of woman participation figure in STEM fields such as social science, biological technology and biomedical. In these fields, it is estimated that over 50 % or participant are female, (National Science Foundation US, 2013).

In conclusion, in developed countries with better gender quality where woman have their voice. The effect of this improvement is still ambiguous, while in 4 main files of STEM, only 20 % are women, this figure is more than double in other sub-areas. One possible explanation is that it depends on social interest framework, (Su et al, 2009), which proves that woman prefer people-orientated jobs compared to thing-related job for man. These preference fully shed light on the reason for gender segregation in different fields of STEM education.

2.3 Educational characteristic

2.3.1 Learning ability measured by test scores

In this research, we used two test result, TIMSS and PISA as an indicator for learning ability for several reasons. Hango, (2013) pointed out in his study in Canada that there is a confirmed link between PISA test score and STEM attendance. In details, student who passed the PISA exams with high score in math at the age of 15 are more willing to attend university with STEM related courses. When the score move from lower level (3^{rd} proficient) to higher level (4^{th} proficient), woman is 7.9 % higher present in STEM higher education when this increase is 6.7 % for man. Moreover, on average, 30 % of people who took the PISA test did chose STEM for their major in the university. This figure is 20 % for woman and 40 % for man, respectively. Finally, Hango, (2013) mentioned that for all students who chose STEM for their major in university, they got 593.4 for the YITS-PISA test. Additionally, Hango also noticed that not only the PISA test can play the role of predictor for STEM education selection later but also the math score in high school. It is concluded that men outperform woman in math in high school but this gap is smaller for top students. It can be seen that when students have better math scores, there is a bigger chance that they will opt for STEM disciplines in university. Mann et al, (2015) support those findings by pointing out that math-science scores has a positive effect on STEM aspiration with the co-efficiency of 0.65. This aspiration is the indicator for potential STEM enrollment later.

How to improve learning ability

It is quite clear in literature that school attendance has a positive relationship on student performance. Even the effects at different grade level and personal abilities are also considered. According to Roby (2014, cited by Aucejo and Romano, 2016), student with higher rate of class attendance tend to outperform students with low attendance rate which in turn the school with average low high daily attendance will perform better in achievement tests. Lee and Barro (2001), mentioned the role of school year length in determining the result of test. They found a positive correlation between math and this fact but a negative one with reading. Whereas, other researchers look at another the side of the story. Absenteeism is investigated for its negative effect on academic performance. In general, it is detrimental to schools and local finance according to Harris, (2014, cited by Aucejo and Romano, 2016). In addition, student performance at school is dependent on their missing days, because it is time-consuming and not effective for them to catch up with their missed lesson. This effect is even more severe on students with low or average ability for study, (Aucejo and Romano, 2016). In general, it could be concluded that more time spent at school by students, the better results are.

We already investigate the vital role of improving show-up time in school in academic performance. For this section, another feature of education which is quality of building and school and its effect on test score are analyzed. Neilson and Zimmerman, (2014) proved that there is a strong link between investment in school facility and better reading score for students. At first, this result is not clear before the year of construction taking place but the long-term effect is observed However, the way this compositional effect affect is still ambiguous. According to their research, there are 3 ways that those effects are under examination. Firstly, better amenities and facility means better lesion taught in school, several classes related to experiments which require latest equipment that cannot be launched before now are available. Secondly, motivation effect is also outstanding, both teachers and students are motivated by the feeling of working and studying in the brand-new building. This effect is even considered to be stronger than the first effect. In a survey later, Neilson and Zimmerman, (2014) ask principals to compare the magnitude of those effects, 9 out of 10 agreed that at least the significance of the second effect is equal to or greater than the first one. Finally, improving school facility on the other hand will lead to the improvement in other type of facilities in students' neighborhood which could result in better study at home.

2.3.2 Teacher-pupil ratio

It could be concluded that quality of education is a dependent variable on teacher-pupil ratio. Ikediashi & Amaechi, (2012) place as much importance as teacher qualification and teaching methodology on this characteristic. Since this one is so vital in determining the quality of any education system, several criteria have been made about effective ratio which depends on the nature of subject with consideration of role of teachers in that class. According to Ikediashi & Amaechi, (2012), theoretical subjects only require a figure of 30:1 (one teacher can handle successfully situations in class up to 30 students) while practical subject' ratio is one the other hand as low as 10:1. The intermediate number is 20:1 if the subject is mixed between two approaches. But the situation is much different when it comes to teacher's role in classroom. Duflo et al, (2007) pointed out 5 roles for a teacher in classroom namely tutor, director, monitor, supervisor and instructor. The figures for them are recommended as 1:1, 10:1, 2:1, 3:1 and from 20:1 to 30:1, respectively. Violation of these well-established figure could result in the lower quality of teaching in classroom because teachers do not have enough time to take care of each individual's needs, (Huebler, 2008 cited by Ikediashi & Amaechi, 2012). Shah & Inamullah, (2012) believed negative and anti-social behaviors are often acquired with overcrowded class which later lead to poor academic performance and higher rate of school dropping out. Therefore, enhancing the active atmosphere in classroom is the essential foundation for teacher to deliver qualitative teaching.

Evasti et al, (2012) found the link between increase of truancy and vandalism when the short-term absence of teacher occurs which means higher ratio of teacher-pupil temporary. It is true that the causality of this relationship is still under investigation, one possible explanation mentioned by Evasti et al, (2012) is that when less teacher available at school due to externalities, the studying atmosphere is very poor. As the result, students tend to misbehave in school activities and class time because they feel not secured and dissatisfied. Moreover, the number of absent days is high, teacher-student relationship is not well maintained and this is a valid predictor for lower school attendance in the future. In conclusion, if this explanation holds its validity, one plausible way to improve school enrollment in general as well as STEM education in particular is keeping teacher-pupil rate at an acceptable figure but not at the cost of teacher quality, Hatsor,(2012). This idea is supported by Valente, (2019) when the author described the situation of Tazania in her research in where the rapid growth of education is observed due to zero tuition fee policy. Along with increase of student enrollment in primary school, Valente also found evidences for higher teacher-pupil rate and worst teacher in recruitment.

To sum up, the essence of appropriate teacher-pupil role has already been confirmed. It not only can help school improve teaching quality which is important for test scores as a way for student fully prove their learning ability but also to keep student active and interested in class time to attract more student to join in education system.

3. Social characteristics

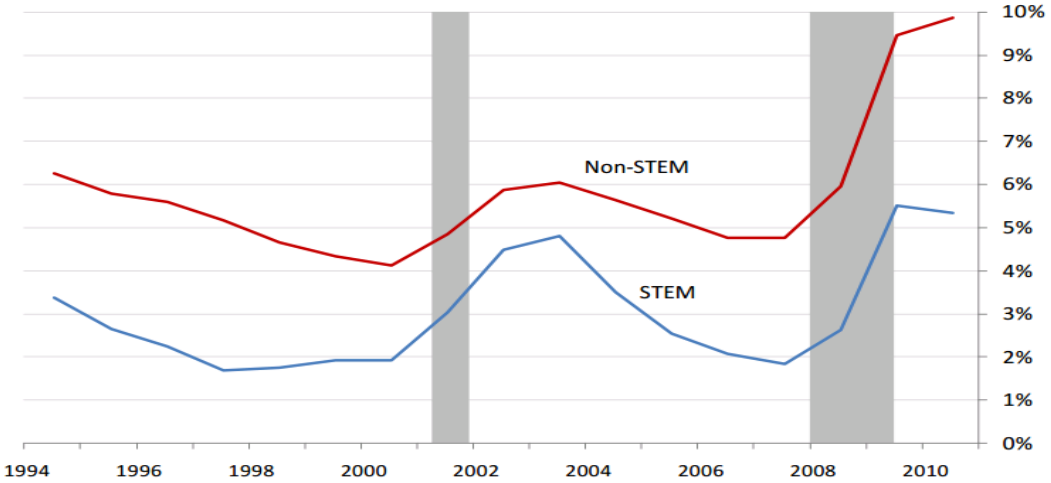
3.1 Fertility Adolescence rate

Kelpinger et al (1995) carried out a research with 2795 women in 12 years before reaching the conclusion that having baby early in life causes negative impact on education achievement of women. According to their study, carrying a baby before 20 will lower the mean year of schooling by 3 years while this effect is less effective for girls who are under the age of 18 with the significance only found for black race of 1.8 year reduction in studying. There several reason are mentioned for this issue, firstly, it is believed conventionally that taking care of baby at the early age will prevent women from attaining economic advantage as well as educational benefits since child caring is time-consuming. Klepinger et al (1995) also mentioned the fact that because women who had children early in their life often dropped out of school which result in lower payment in the labor market where the salary is and dependent variable of qualifications. This is the cause for less educational investment later because limited budget earned from low-paid job. Narita & Diaz, (2016) confirmed this link again in their investigation in Brazil. In this paper, they examined the effect of young motherhood of 4 different factors including average wage, total year of study, the rate of which high school is completed and percentage of women present in working labor market. It is concluded early motherhood is inverse proportionate to all those 4 factors but with difference attitude. The strongest effect are found in the mean of school year with the co-efficiency of -2.79. Further indication from this research is about life cycle's effect when it shows the greater difficulty to keep pace with missed classes when women get older.

3.2 Unemployment rate

Hand & Skolnik, (1975) carried out a research to fill in the gap between unemployment and school attendance. While it is commonly claimed that fear of unemployment is an encouragement for school participation, the finding of their study is against this belief. These author confirmed that high unemployment rate is not significant on increasing the school enrollment rate. What is the strong driving force for educational investment is the economic benefit of working. According to Hand & Skolnik, (1975) 10 % increase in projected wage will result in 20 % rise in post-graduate participation. For the case of STEM, it is proved partly by Beede et al, (2011) by pointing out that women earn 33% more for doing STEM jobs. This wage gap is less for both genders with only 29 %, Noonan, (2017). Whereas, Kodde, (1988) cited the work of Nickell, (1979) that pointed out the negative relationship between unemployment and years spent at school. One explanation is that by taking into account lower rate of unemployment observed for people with higher qualification, students measure all the benefits before make up their mind. The unemployment rate is considered to be lower for STEM qualification holder which in some case can mean that the school participation could be higher for students who want to do STEM courses with other effects stay the same. However, more evidences and empirical research need to be carried out to confirm the validity of this proposal. This unemployment gap is illustrated as the following graph.

Figure 3. Unemployment Rates in STEM and Non-STEM Occupations, 1994-2010



Soure: David et al, (2011).

There is common hold belief that America in particular and the whole world is suffering from the shortage of employees for STEM related fields. In the 21 first century, STEM is considered to be the core competences for every country to stay competitive on international market. However, according to Xue & Larson, (2015) this is not true for all the fields of STEM. While nuclear and engineering are facing the shortage of student as well as competent workers, the case is inverse for Biology. However, with the prediction of continuous

increasing requirement for STEM workforce, Noonan, (2017) estimated that by 2024 the STEM labor market is expected to see the growth of at least 8.9 percent compared to only 6.4 percent for non-STEM jobs. In conclusion, the unemployment rate is negatively correlated to educational attainment because of expectation of higher benefit in the future. This finding is still ambiguous for STEM despite the fact that STEM job pool has the lowest rate of unemployment as well as the higher wage compared to other occupations.

4. Government characteristic:

Government intervention can play a vital role in improving both education quality and school attendance. This claim is based on the foundation that the market of education is imperfect by externalities which can be fixed and the outcomes would be better thanks to government policies. Firstly, Cohn and Geske, (1990, cited by Poterba, 1996) mentioned the positive externality of school which includes better democracy for that country and production ability. Because Cohn and Geske believed that well-educated people are more willing to raise their voice to contribute to their government and their co-workers also have chance to be better-off by peer-studying. Secondly, Cohn and Geske, (1990) also claimed that the relationship between crime and education is negative. While those benefits are not associate to the learner itself, it is very important for the society as the whole. Poterba, (1996) also added one more point of social integration for immigrants as long as they are provided with the equal level of education. However, when parents are the one who pay for school and they do not evaluate probably all the benefits of school, it is likely that they will not spend enough to reach to the point which maximize social welfare. This is the time that we need government to interfere through different mechanism such as education subsidies, mandates or government provision to make sure this efficient level reached. Even when parents are fully aware of total benefit for spending on their children's studying, budget constrain is another problem. In order to tackle this problem, Porterba, (1996) recommended price subsidies such as scholarship or free interest for loan made by students to go to school.

Moreover, Gupta et al, (2002) cited that public spending on education is really matter in school attendance, (Ogbu& Gallangher, 1991). In particular, Mehrotra, (1998, cited by Gupta et al, 2002) used data from 10 countries for his research and then found out that higher figure of school attendance is attributed to more spending on education. Gupta et al, (2002) later reconfirmed these finding by analyzing cross-section data from 50 countries before concluded that public spending on primary and secondary school are important to increase the rate of school enrollment. They pointed out that 5 increase in budget allocated for school at primary and secondary level would result in 1 percent increase in total number of student in secondary school.

Eicher et al, (2009) mentioned the quality of government as the key condition for development of education. While corruption at first will lower the amount of finance spent on education which in turn disable the government from their role in fixing market failure mentioned above. Moreover, they also discovered that because well-educated students when participate in political system pose higher risk for corrupted behaviors to be detected, it is likely that the corrupted government will pass down the law to eliminate corruption in the future. The result of this stage is really dependent on the original condition of each country. Mauro, (1998) confirmed the idea of negative relationship between corruption level and expenditure on education. He also added that this relationship in not strongly affected by adding other factors such as GDP, he suggested that because the rents generated by education for corrupted officer is not very attractive. In conclusion, in order to improve the quality of education system and allow more students to go to school, corruption should tackled properly in order to enable the role of government in fixing negative externalities caused education market.

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