The importance of science, technology, engineering, and mathematics (STEM) education to enhance students’ critical thinking skill in facing the industry 4.0

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Abstract. The industry 4.0 marks the fast-growing technology in many fields in order to achieve process efficiency in all of aspect of the industries, including education. The efficiency is derived from a big data, a real-time dataset collected from a vast amount of data from many instruments. Big data processing is used to predict market trends, discover new problem-solving and many more. Critical thinking, statistics, computing and the ability to understand how the world works are among important factors that has to be needed in big data processing. Among those abilities, critical thinking is an essential ability influencing directly the big data processing because this ability can aid students to decide the best alternative solutions in solving a problem. Nevertheless, the lack of good educational platform to host such important skills in the current Indonesian education makes it harder to cultivate good human resources that are able to comprehend big data processing. Science, technology, engineering, and mathematics (STEM) is known to be the holistic educational approach that combines various disciplines into one set of educational approach to help students gain more skills and sharpen their knowledge in regards of the fast-growing industry 4.0 in Indonesia.

1. Introduction
The fourth Industrial Revolution (the industry 4.0) is the currently fast-growing and rapid development of digital technologies in many fields such as, manufacture industries, science industries, entertainment industries, communication industries, political industries and education industries [1]. Industry 4.0 as the agile movement that includes smart usage of manufacturing systems which products are not simply connected or integrating digitally, but also they are able to communicate, analyze and use the information to face the uncertainty of the future [2]. Hence, the operating industry in the Industry 4.0 is the using of advanced sensors and information technologies in which vast amount of data that is called as “Big Data” is generated and collected for the better use.

Big Data is a distribution of voluminous sets of data which requires advanced technologies, techniques and skills to enable the capture, distribution, management and analysis of the information that will enhance insight to make a better decision making or develop an advanced process of
automation. Consequently, the collected data need to be further analyzed in order to extract and obtain valuable information [3]. In consequence, the results of the analysis can be used as insights to optimize decision-making, and become a vital data in both academic research and practical application.

A data analyst is someone who must have the ability to analyze meaningful and relevant data as well as converting them to more meaningful knowledge that can be used to optimize processes [4]. According to the World Economic Forum forecast [5], data analyst will be in high demand in the future, because it will be needed by companies or organizations in wide range of industries. In the other words, data analyst is a person who must have an ability to analyze meaningful and relevant data and convert them to information, knowledge.

Critical thinking skill is one of the essential soft skills that a data analyst must have [6]. In addition, critical thinking is a manner of thinking that employs curiosity (wanting to learn), creativity (viewing information from multiple perspectives), skepticism (maintaining a ‘trust but verify’ mindset), analysis (systematically examining and evaluating evidence), and logic (reaching well-founded conclusions) [7]. Critical thinking skill is not only being the only skills that a data analyst should have, but also the collaboration of analytical techniques such as regression, simulation, machine learning analysis and data science [8]. The analytical skills that is needed here includes skills that are being taught in school education such as in the fields of Mathematics, Computer, Engineering and Science.

In Indonesian education, critical thinking is seen as one of important goals because it helps developing students’ ability to face the rapid-growing of Industry 4.0 where not only one skill is required, but a holistic series of skills are needed. Wilson [9] stated that critical thinking skill can affect students’ potential directly by applying series of information effectively so they can decide the best alternative solutions in solving a problem such as processing a big data. So, it is required to prepare an education program that it is not only can drill the critical thinking skill, but also can integrated mathematics, engineering, technology, and even science in order to have the better comprehension about big data. Science, Technology, Engineering, and Mathematics education (STEM) is one of the appropriate education programs to address this challenges in regards to the industrial revolution 4.0 [10].

STEM is the integration of science (S), technology (T), engineering (E) and mathematics (M) which relates to both workforce and daily life experiences. STEM is relevant because in the nature of the world, each discipline (S-T-E-M) does not exist alone and complex and multidimensional problems are encountered by all [11]. Besides that, STEM can give students opportunity to apply concepts and knowledge from various disciplines in an integrated way to solve problems in the real world. In an addition, they can involve actively in learning activities that promotes the use of hands-on activities that links to the real-world problems by encouraging them to seek and to gain a deep understanding of the activity that is being carried out [12,13]. In one hand, Morrison [14] stated that STEM educates students to be a critical thinker. Thus, STEM can shape student’s ability such as critical thinking and industrial mindset to face the rapid-growing industry 4.0.

In the Indonesian education, STEM is quite similar with the current 2013 curriculum that focuses on the curriculums integration [15] or so called as the thematic integrated learning. Thematic learning is one of the learning approach used to recognize symptoms and concepts from various disciplines [16]. According to the Minister of Education and Culture No. 67 of 2013, in the curriculum 2013, this approach is only implemented for primary education (grade 1 - 6) [17]. Seeing how STEM can be a solution to create a good human resources, this method is very likely can be the breakthrough of the educational model to face the Industry 4.0 for its flexibility to be implemented to other related subjects in all education level [18].

2. Methods
This article is a content analysis that based on some articles and books related to the education in industry 4.0. The aim of this study is to give new insights about teaching and learning activities in industry 4.0, especially Mathematics teaching in Indonesia.
3. Result and Discussion

3.1. Industry 4.0

Industry 4.0 is an as an integrated, adapted, optimized, service-oriented, and inter-operable manufacturing processes which correlate with algorithm, big data, and high technologies [19]. The higher level manufacturing operation and other technical or communication approaches the more efficient the use of machine automation in the Industry 4.0 [20,21]. These characteristics are able to make people to be more agile, flexible, and responsive that enable them to connect and communicate in real-time anywhere and anytime [22]. The advancement of industry 4.0 includeshow people become smarter by constantly learning and improving their skills with a high adaptability in various kind of environments with the integration of technology [23].

The industry 4.0 which was the next industrial era is initiated with the fast-growing technology such as; The present of Internet of Things (IOT), the development of mobile solutions like smartphones, tablets, wearable sensors and smart glasses, the advancement of cloud computing such as low-cost processing and data storage solutions, Cyber-Physical Systems (CPS), big data analytics and business intelligence, advanced manufacturing technologies that include robotics and 3D printing [24], internet and telecommunication industry [25].

It is wisely stated that in the industry 4.0 people are beginning to use smarter and more efficient tools to support their work and daily need. The industry 4.0 can be said to be more demanding in terms of the human resources itself because without sufficient skills and without appropriate skills, then they will be left off.

3.2. Big Data

Big data was introduced in 2005 to the computing world to define a great amount of data that traditional data management technique cannot manage and process due to the complexity and size of the data [26]. Big data is the information asset characteristics by such as a high volume, velocity, veracity and variety to require specific technology and analytical methods for its transformation into a value [27].

According to The Economist big data is an important part in the industry 4.0 as companies and organizations such as in government, e-commerce, and health organizations through web-based sites, mobile applications, and sensory devices or systems at a terabyte and in some instances even at a Exabyte scale will generate an enormous amount of data. The analysis system of big data is able to go over the barrier of the existing knowledge and to make new discoveries [28]. Later George, Haas, and Pentland [29] stated that the predictive nature of the big data analysis is the key role in every organization and company decision-making processes. It can be concluded that big data usage to help in decision-making processes gives power to organization or company to personalize their services, improve customer service, and predict future actions. In order to process such vast data to be able to create an insightful information for better use, a critical thinking skill is urgently required in big data analysis.

3.3 Critical Thinking Skill

Critical thinking as a mental activity that involves: identification (knowing and understanding), examination and verification as well as result evaluation [30]. According to Beyer [31] critical thinking is a thinking process that is used by someone to evaluate and validate any kind of information he/she received. It can be said that critical thinking is a skill to analysis, interpret, explain, evaluate, observe and examine over own thought [32]. Someone who has this skill is defined as a critical thinker, a person who has the capability to solve a crucial problem by; gathering and assessing a relevant information and also concluding a reasonable solution. Paul and Elder [33] stated that a critical thinker would also have the traits to be open minded in identifying and assessing assumptions, implications and they also will always be aware of the consequences by always communicating with others.
3.4 STEM

STEM is an abbreviation of science, technology, engineering and mathematics taught and applied either in a traditional and discipline-specific manner or through a multidisciplinary, interconnected and integrative approach that aim to solve real-world challenges [34]. In a problem solving manner, STEM has some principles as follows; using critical thinking to recognize a problem, using math, science, technology, and engineering concepts to evaluate a problem, and correctly identifying the steps needed to solve a problem (even if not all the knowledge to complete all steps is present).

3.5 The Implementation of STEM to Enhance Critical Thinking Skill

The first to state that science in STEM uses empirical evidence and logical inference to identify generalizable principle that explain the mechanisms of natural phenomena that is currently or has been happening [36]. So, it can be referred that processing information through science perspective gives student a clear way or rather undisturbed perspective of seeing things as they are to be well explained. Then, according to Koen [37] from the engineering perspective, to accomplish goals an engineer should use an empirical evidence with very logical approaches. This way, an executible step will be generated that is actually like what is needed. Mwakapenda [38] stated that from mathematics point of view that the mathematical problem can shape students the way of thinking in a process of understanding how the world/problem works. Lastly, according to Dugger[39] technology involves concept and principle that can incorporate students’ direct experience at all levels. So, in combination of science, techno which can lead students to enhance their critical thinking skill [40].

The integration of this approach consists of four areas which are; intradisciplinary, multidisciplinary, interdisciplinary and transdisciplinary. The intradisciplinary is a combination of two or more topics in one subject. The multidisciplinary is a combination of two or more subjects in the same set of knowledge. The interdisciplinary is a combination between two or more subjects but in the different kind of knowledge. The transdisciplinary is a combination between one of the subjects that being taught in school with other set of knowledge that is not taught in school [12]. According to Morrison [14], this integration aims to remove the traditional barriers that has been there among the science, technology, engineering and mathematics in which those disciplines are thought to be not connected to one another.

Speaking of the combination of those disciplines to create some meaningful inventions, every technological advancement that we enjoy today were built from the mathematics foundation. Mathematics has been a very crucial part in each of the century’s invention to make our lives easier or more productive. In mathematical point of view, the patterns of mathematical thought were explored through formalized semiotics in which is basically the study of symbols and algorithms. Then, science will use the symbols and algorithms of mathematics to derive the formulas and procedures which allows scientist to provide a physical verification of the concept. The engineering disciplines will build the realization of the plan by designing and transforming intellectual conceptions into tangible product. The technology will develop a model by improving and legitimizing the tangible products to achieve what is so called as the efficiency. All those combination should be executed appropriately to become a large scale of intellectual improvement and intellectual processes [41]. The connection of those combination is briefly explained below (see Figure 3) [42].
Based on the above diagram, STEM approach is being designed as student-centre approach by cooperative learning in small groups, in which teacher acting as a facilitator in learning activities. Refer back to the industry 4.0 education in which learning activity is a learner-centred (connected to the learner, focused on the learner, demonstrated by the learner and led by the learner), FICCI [43] stated that the instructional strategies that can enhance innovation in STEM is by applying learning based-problem (Problem-based learning) and based-project (Project-based learning) [12]. Big data processing that requires critical thinking skill as one of the important keys in the industry 4.0, this learning approach is seen to be the most appropriate way to approach students to learn more skills. Big data requires advanced technologies, techniques and even skills like critical thinking skill to enable extract and obtain valuable information. The results of the analysis can be used as insights to optimize decision-making in solving a problem or can be used as a vital data in both academic research, practical application, as well as to predict future trends. Hence, STEM is one of set of educational approach aiding students to sharpen their critical thinking skill, so they are able to face the fast-growing industry 4.0 especially in Indonesia.

4. Conclusion
The implementation of STEM (Science, Technology, Engineering, Mathematics) is one of learning approach that are considered appropriate for to prepare students skills and awareness of the fast-growing era of the industry 4.0. The STEM education is an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems. By engaging students around the subjects of Science, Technology, Engineering, and Math, STEM aims to enhance critical thinking skill that will prepare students become innovators in an evolving world, so they are able to address this challenge in regards to the industrial revolution 4.0, such as big data.

5. References
[1] Schwab K 2017 The fourth industrial revolution New York: Crown Business Press
[2] Sniderman B, Mahto M and Cotteleeer M J 2016 Industry 4.0 and Manufacturing Ecosystems USA: Deloitte University Press
[3] Mohammadpoor M and Torabi F 2018 Big Data analytics in oil and gas industry: An emerging trend Petroleum pp 1–29
[4] Bumblauskas D, Nold H, Bumblauskas P and Igou A 2017 Big data analytics: transforming data to action Bus. Process Manag. J. 23 3 pp. 703–720
[5] Schwab K Samans R 2016 World Economic Forum: The Future of Jobs Report
[6] Forfás 2014 Assessing the Demand for Big Data and Analytics Skills, 2013-2020 Group on Future Skills Needs
[7] Reding, K. F., & Newman, C. (2017). Improving critical thinking through data analysis: the process for analyzing data provides accountants, financial managers, and auditors an opportunity to develop and grow their critical thinking skills. Strategic Finance, 98(12), 48-55.
[8] Watson H J 2014 TutorialBig Data Analytics Concepts Technologies and Applications Commun. Assoc. Inf. Syst. 34 65 pp. 1247–1268
[9] Wilson M 1988 Critical thinking: Repackaging or revolution? Lang. Arts 65 6 pp. 543–551
[10] Kirchner M D 2017 Teaching the Industrial Internet of Things Preparing Students and Learners for Industry 4.0 Mequon
[11] Talley T 2016 The STEM Coaching Handbook: Working with Teachers to Improve Instruction. New York: Routledge
[12] Baharim N, Kamarudin Nand Manaf U K 2018 Integrating STEM Education Approach in Enhancing Higher Order Thinking Skills Int. J. Acad. Res. Bus. Soc. Sci. 8 7 pp. 810–822
[13] Shahali E H M, Halim L, Rasul M S, Osman K, and Zulkifeli M A 2017 STEM learning through engineering design: Impact on middle secondary students’ interest towards STEM EURASIA J. Math. Sci. Technol. Educ. 13 5 pp. 1189–1211
[14] Morrison J S 2006 Attributes of STEM education: The students, the academy, the classroom Baltimore: Teaching Institute for Excellence in STEM
[15] Setiawaty S et al. 2018 Science, Technology, Engineering, and Mathematics (STEM) Learning on Student’s Science Process Skills and Science Attitudes in Proceeding of MICoMS 2017 pp. 575–581
[16] Wati, U.A., 2010. Pengembangan Multimedia Pembelajaran untuk Mata KuliahPembelajaran Terpadu. JurnalPenelitianIlmu Pendidikan. Yogyakarta: FIP Universitas Negeri Yogyakarta.
[17] Depdiknas 2013 Peraturan Menteri Pendidikan dan Kebudayaan Indonesia
[18] Ejiwale J A 2013 Barriers to Successful Stem Implementation J. Educ. Learn. 7 2 pp. 63–74
[19] Lu Y 2017 Industry 4.0: A survey on technologies, applications and open research issues J. Ind. Inf. Integr. 6 pp. 1–10
[20] Abbas S A 2018 Entrepreneurship and information technology businesses in economic crisis Entrep. Sustain. Issues 5 3 pp. 682–692
[21] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M., 2015. Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group, 9(1), pp.54-89.
[22] Leung, S.W., Mak, S. and Lee, B.L., 2008. Using a real-time integrated communication system to monitor the progress and quality of construction works. Automation in construction, 17(6), pp.749-757.
[23] Tvenge N and Martinsen K 2018 Integration of digital learning in industry 4.0 Procedia Manuf. 23 pp. 261–266
[24] Wang, L. and Wang, G., 2016. Big data in cyber-physical systems, digital manufacturing and industry 4.0. International Journal of Engineering and Manufacturing (IJEM), 6(4), pp.1-8.
[25] Geissbauer R, Schrauf S, Koch V and Kuge S 2014 Industry 4.0 – Opportunities and Challenges of the Industrial Internet London: PricewaterhouseCoopers
[26] Ularu E G, Puican F C, Apostu A, and Velicanu M 2012 Perspective on Big Data and Big Data Analytics Database Syst. J. 34 pp. 3–13
[27] De Mauro A, Greco M, and Grimaldi M 2016 A formal definition of Big Data based on its essential features Libr. Rev. 65 3 pp. 122–135
[28] Waller MA and Fawcett SE 2013 Data science predictive analytics and big data A revolution that will transform supply chain design and management J. Bus. Logist. 34 2 pp. 77–84
[29] George G, Haas M and Pentland A 2014 Big Data and management Acad. Manag. J. 57 2 pp. 321–326
[30] Yinger R J 1980 Can we really teach them to think? *New Dir. Teach. Learn.* 1980 3 pp. 11–31
[31] Beyer B K 1995 *Critical Thinking* Bloomington: Phi Delta Kappa Educational Foundation
[32] Facione P A 2000 The Disposition Toward Critical Thinking: Its Character, Measurement, and Relationship to Critical Thinking Skill *Informal Log.* 20 1 pp. 61–84
[33] Paul B R and Elder L 2008 The Miniature Guide to Critical Thinking: Concepts & Tools The Foundation for Critical Thinking
[34] Fitzallen N 2015 STEM Education: What Does Mathematics Have To Offer? in *Proceedings of the 38th annual conference of the Mathematics Education Research Group of Australasia* pp. 237–244
[35] Thomasian J 2011 *Science Technology Engineering and Math.* Washington DC: National Governors Association
[36] Blackburn S 1999 *Think: A Compelling Introduction to Philosophy* London: Oxford University Press
[37] Koen B 1985 *Definition of the Engineering Method* Washington DC: American Society for Engineering Education
[38] Mwakapenda W 2008 Understanding connections in the school mathematics curriculum *South African J. Educ.* 28 2 pp. 189–202
[39] Dugger W E 1993 The relationship between Technology, Science, Engineering and Mathematics *Annu. Conf. Am. Vocat. Assoc.* pp. 1–18
[40] Rudinow J and Barry V E 2008 *Invitation to Critical Thinking* USA: Thomson Wadsworth
[41] Ostler E 2012 21st Century STEM Education: A Tactical Model for Long-Range Success *Int. J. Appl. Sci. Technol.* 2 1 pp. 28–33
[42] Sheffield R 2018 A Makerspace Approach for STEM Education *Presented in Workshop of Science and Mathematics International Conference* [Image]
[43] FICCI 2017 *Leapfrogging to Student at the core* New Delhi: FICCI

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