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Integrating STEM into the Formal and Instructional Curriculum to Support Machine Construction Design

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Abstract. The design of machine construction is one of the subjects that often becomes a stumbling block for students of the Mechanical Engineering Education Study Program to graduate on time. Many factors cause it, including the weakness of students using STEM content in designing machine construction and the lack of contextual learning strategies for STEM-loaded courses with machine construction design tasks. This qualitative study aims to identify the STEM content of the Scientific and Expertise Subject group, describe the pattern of integrating STEM content in the formal and instructional curriculum, and describe the learning pattern of the STEM content course. Research data were collected through document analysis, semi-open questionnaires, and FGD. The results showed identified 15 scientific and skill courses containing STEM content that supported the work on machine construction design tasks, integration of STEM-loaded courses in the formal curriculum was carried out by structuring their presentation before or at the same time as the presentation of the Mechanical Construction Design Course, being in the instructional curriculum is carried out by integrating learning experiences related to the design of machine construction in Lecture Event Unit, and the learning pattern of courses containing STEM content should be carried out using a problem-based learning model where the problems are directly related to and or taken from machine construction design tasks.

Keywords: STEM, formal curriculum, instructional, design, machine construction

INTRODUCTION

The engineering construction design (ECD) is one of the courses that often becomes a stumbling block for students of the Mechanical Engineering Education Study Program (MEESP), Faculty of Engineering, State University of Malang in completing their studies. Information submitted by the Head of Mechanical Engineering Department at each end-of-semester evaluation meeting shows that (1) the average completion time of writing an ECD is two semesters, some even more; (2) among the obstacles faced by students are (a) the high demands of lecturers on engineering construction that must be produced by students where the novelty element must be shown by the existence of the latest IT applications, (b) the writing still has to be completed by students individually, and (c) the weakness of students in the field of electrical systems in the ECD; and (3) the low quality of ECD products.

In the MEESP, the Engineering Construction Design Course (ECDC) is product-oriented. The study materials include (a) making an initial design, (b) making an engineering design, (c) making a manufacturing design, (d) compiling the results of a product design in the form of a written report, (e) making a proposal of Student Creativity Program (SCP) based on the results of the design made, and (f) be responsible for the results of the product design in the examination (2020 MEESP Curriculum). The starting point for the tasks of ECD must be based on preliminary study activities through observation and investigation of various technical problems in the community (Concepts, 2011). In general, ECDC is carried out in a tutorial/guidance manner where each student must start by submitting the main idea based on the results of his/her preliminary study accompanied by the title of ECD to the MEESP Coordinator. After being judged worthy, the MEESP Coordinator appoints a candidate for the advisory lecturer (AL) to approve the title or problem of ECD and approval for his/her appointment as an AL. Based on the approval of the AL candidate, an AL Assignment Letter is issued by the Faculty of Engineering Dean, State University of Malang.

Completion of ECD tasks is integrative. To do an ECD taks, students must be able to integrate various disciplines at once, especially the four disciplines incorporated in STEM (science, technology, engineering, and mathematics). This follows the principle of the STEM approach, which combines science, technology, engineering, and mathematics into one class based on connections between subjects and real-world problems (Stohlmann et al., 2012). The application of the STEM approach can also improve students' critical thinking skills, which are characterized by the ability to solve problems, make decisions, analyze assumptions and evaluate (Khoiriyah et al., 2018), which underlies the work of ECD task. Therefore, students' mastery of the four disciplines will determine the fluency and quality of their ECD product. Unfortunately, these four disciplines often have not been or even not by design to facilitate students in completing their ECD task in the form of a STEM approach.

STEM has several meanings depending on the point of view, when viewed from the context of the learning approach, STEM means a meta-discipline where science, technology, engineering, and mathematics teachers teach in an integrated manner, and each discipline material is not separated but is handled and treated as a dynamic unit (Brown et al., 2011). In line with that statement (Reeve, 2013) defines STEM as an interdisciplinary approach to learning in which students use science, technology, engineering, and mathematics in real contexts that link school, the world of work, and the global world.

In the context of learning, the STEM approach is not only meaningful as strengthening learning praxis in STEM fields separately but is the development of a learning approach that integrates STEM content with the focus of the learning process on solving real problems in everyday life and professional life (National STEM Education Center, 2014; Rustaman, 2016). The main characteristic of the STEM approach is that it integrates science, technology, engineering, and mathematics in solving real-world problems (Word, 2015). In practice, it is challenging to combine STEM learning into a single unit that emphasizes the relationship between the four disciplines because it will affect learning effectiveness (Barakos et al., 2012). In that context, Roberts (2012) classified applying STEM learning into three approaches, namely (1) separate (SILO), (2) embedded, and (3) integrated approach. The SILO approach emphasizes independent learning for each STEM subject (Winarni et al., 2016) or no integration between STEM subjects (Anggraini & Huzaifah, 2017). Through an embedded approach, domain knowledge is gained by emphasizing real-world problems with problem-solving techniques (Chen, 2001). The difference with the SILO approach is that the accompanying material is not assessed and only acts as a reinforcement of the primary material. In the integrated approach, each STEM subject integrates into a unified whole, starting with identifying real problems in the environment around students through high-level thinking and problem-solving abilities (Wang et al., 2011).

In its implementation, STEM learning faces many obstacles. Ejiwale (2013) identified six barriers to STEM learning: lack of connection with students, lack of support from the school system, lack of collaboration across STEM fields, poor content preparation and delivery, inadequate facility conditions, and lack of hands-on training for students. Study Kurniawan et al., (2019) about the various characteristics of STEM in the design of engineering construction of the MEESP students of Faculty of Engineering, State University of Malang concluded that students faced internal and external obstacles. Internal barriers in the form of students' difficulties when using STEM course content to solve problems in the design of engineering construction, while external obstacles STEM from the learning methods/lectures of the lecturers who are less or not even contextual with problem-solving in the design of engineering construction. Regarding opinion of Ejiwale (2013), both types of student difficulties are classified as difficulties due to lack of collaboration across STEM fields, poor content preparation and delivery, and lack of support from the collage system.

Based on this explanation, this study aims to (1) identify of STEM content in various courses in the MEESP of Faculty of Engineering, State University of Malang that have the potential to be used in the ECD by students; (2) describe the pattern of integrating potential STEM content for the ECD in the formal curriculum and instructional curriculum; and (3) describe the learning patterns of STEM-loaded courses to support improving the quality of students’ ECD products.

METHODS

This research was conducted using a qualitative research method with a descriptive design. The data sources for this research are (1) the Head of the Mechanical Engineering Department/Coordinator of the MEESP, (2) the lecturers who teach courses containing STEM content in the MEESP, and (3) the MEESP lecturers who have previously taught/served as supervisors is taken/determined in accordance with the adequacy principle. The research data were collected using semi-open questionnaires, and analysis of the 2020 formal curriculum documents of the MEESP, and the ECD Report documents for the MEESP students with a focus on analyzing the STEM content in the curriculum, and analyzing STEM content used by students in writing/working on ECD assignments.

Checking the validity of research data was carried out through FGD (focussed group discussion) activities with a focus on the study of the final draft of the research findings in the form of identifying STEM content needed in the ECD, patterns of integrating STEM content in the formal and instructional curriculum, and learning patterns of STEM-loaded courses. Data collection and analysis were carried out interactively as intended by Miles and Huberman (1994).

RESULTS AND DISCUSSIONS

Identification of STEM Content in Various Courses Potentially Used in ECDC

An in-depth analysis of the 2020 MEESP Curriculum document resulted in 15 courses containing STEM content that students could potentially use in working on ECD. Confirmation of the analysis results to the lecturers through a questionnaire showed that most of the lecturers of the MEESP (78.57%) agreed with the analysis results. Meanwhile, a small proportion (21.43%) proposed issuing the CAM course and including the Engineering Materials Course as a STEM-loaded course that supports the ECD. Triangulation of research findings through FGD strengthens the two previous research results so that the classification of STEM-loaded courses in the 2020 MEESP Curriculum is produced, as shown in Table 1. While the results of the identification of STEM content in each of these courses are shown in Table 2.

Table 1 Classification of scientific and expertise courses containing STEM

No.	STEM Classification	Courses Name
1.	Science	Engineering Physics, Engineering Chemistry, Engineering Materials
2.	Technology	Engineering Drawing, Engineering Construction Drawing, CAD, Engineering Assembling and Installation, Energy Conversion, and Mechatronics
3.	Engineering	Materials Mechanics, Fluid and Thermal, Engineering Statics and Dynamics, and Machine Elements
4.	Mathematics	Engineering Mathematics
5.	STEM	Basic of Engineering Constructions Design

Table 2 Identification of STEM content of science and expertise courses potentially used in ECDC

No.	STEM Classification	Course Name	STEM Content
1.	Science	Engineering Physics	The concept of motion procedures, the use of electricity and magnetism, the use of fluids and thermals, the use of renewable alternative energy, business and energy.
		Engineering Chemistry	Draft stoichiometry and the basic laws of chemistry, the periodic system, atomic structure and bonds, energy and materials fields, corrosion and its environmental causes, water for steam boilers and steam turbines, polymers, lubricants, metal coatings.
		Material Mechanics	Concepts, principles, and basic engineering procedures and material workmanship as the basis for applying engineering/manufacturing processes.
2.	Technology	Engineering Drawing	Concepts, principles and practical procedures regarding the types and functions of lines and technical drawing equipment, types of projection drawings, typefaces, numbers, dimensions, size indications, workmanship signs and symbols, cuts, arrangement drawings, object projections, workmanship marks and tolerances.
		Engineering Construction Drawing	Drawings of machine components, bolts, nuts, gears, and couplings, pegs, shafts, axles; drawing components and arrangements/assemblies manually as a basis for computer drawing (CAD).
		CAD	The concept of drawing with a computer program (CAD), the principle of line elements and element modification (cutting, joining, copying, deleting, rotating, and projecting, 2D and 3D drawing, principles of drawing

No.	STEM Classification	Course Name	STEM Content
			layout and printing, animation of functional assemblies of designed products, and analysis) product modeling.
		Engineering Assembling and Instalation	Variety and function of assembly equipment, assembly aids, variety of components and product component positions, making layouts, foundations, machine installations, *leveling* and aligning, testing the machine.
		Energy Conversion	The concept of energy in general, energy sources, various types of energy conversion, and the types, ways of working, uses and advantages of energy conversion machines (thermal, fluid, electricity, wind, and steam).
		Mechatronics	Mechatronics concepts and applications, the main devices of mechatronic systems and their functions; working principle, characteristics, and application of various types of sensors and transducers (linear and rotation, acceleration, force, torque, flow, temperature, distance, light, vision, integrated microsensor), function and working principle of actuators (electric motors, hydraulic , pneumatic, electromechanical), signal conditioning in mechatronics, micro-control programming, programming with PLC, designing mechatronic systems, mechatronic system applications, evaluating the application of mechatronic design results, analysis of mechatronic design applications.
3.	Engineering	Material Mechanics	Analysis of stress and strain types, moment of inertia, various types of stresses and stresses in beams, deflections, certain and indeterminate statics, and software applications for stress analysis.
		Fluid and Thermal	Concepts and procedures, systems and units, fluid statics, thermodynamics.
		Engineering Statics and Dynamics	Concepts of statics and dynamics, analysis of force, resultant, loading on rigid bodies, particle kinematics, kinematics of rigid bodies (shafts, gears, cam shafts), mechanical vibrations, and performing statics and dynamics analysis with software applications.
		Machine Element	The concept of theoretical principles and procedures for standard and standard components, variety and function of machine elements, properties, main sizes, standardization of machine elements to support students' abilities in machine design courses.
4.	Mathematics	Engineering Mathematics	Concepts and procedures for using vectors, differentials, integrals, differential-integral equations, derivatives, functions, graphs, differential equations.
5.	STEM	Basic of Engineering Constructions Design	The design concept is reviewed from various points of view, the design process, the initial design (draft design), engineering design, manufacturing design, calculation of component strength (shafts, bearings, pins, pulleys, gears, and the like) in terms of various types of loading, manufacturing design a product, manufacturing modeling.

Patterns of Integrating STEM Content in the Formal and Instructional Curriculum

Structurally the Formal Curriculum of the 2020 MEESP is presented based on the semester learning load and scientific hierarchy accompanied by a description of each subject. Analysis of the presentation of various groups of STEM-loaded courses that are potentially used in the ECD shows that most (92.86%) of these courses are presented before the presentation of the ECDC, which is presented in the fifth semester. While one course (7.14%), namely Mechatronics Course, is presented in the sixth semester. The results of data triangulation through FGD concluded that the Mechatronics course has STEM content neded in the ECD. Therefore, it was agreed that the presentation should be aligned with the ECDC, namely the course in the fifth semester. It was agreed that the presentation of the ECDC would be given in the fifth semester so that the completion would not collide with the essay (skripsi) work. The linkage of various STEM-loaded courses and ECDC in the 2020 MEESP Curriculum is shown in Figure 1.

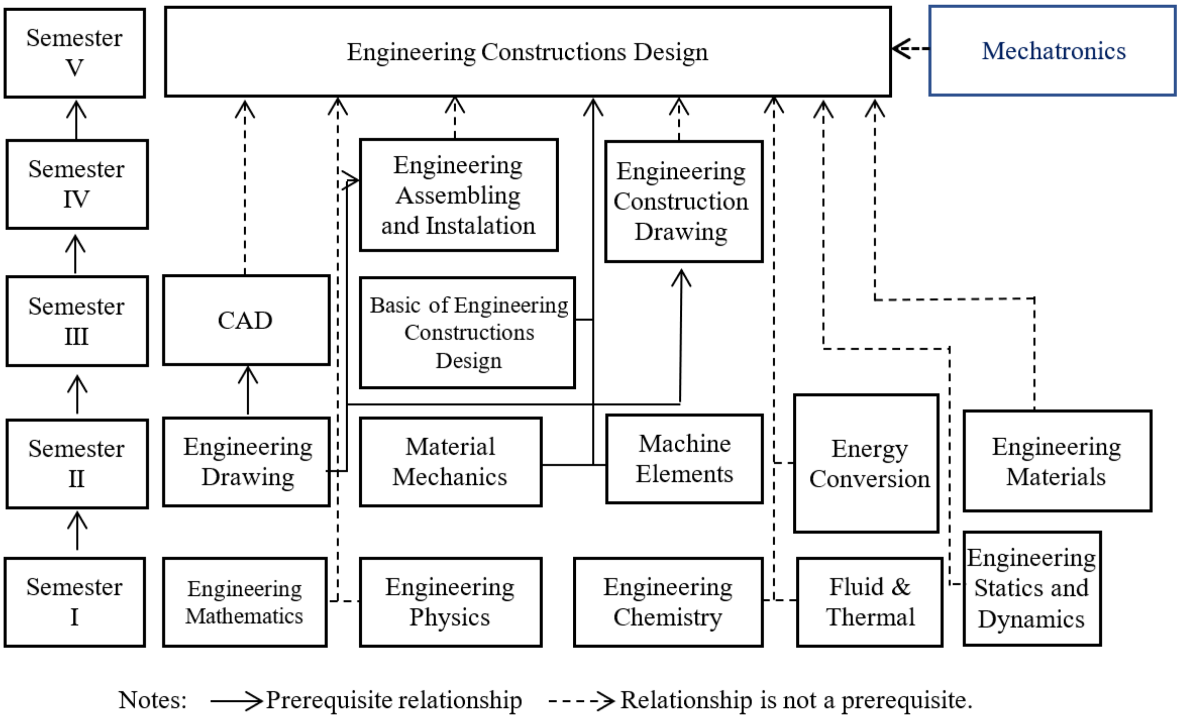

Figure 1 Schematic of the relationship between STEAM-loaded courses and ECDC according to the 2020 MEESP Curriculum.

The Formal Curriculum pattern for the 2020 MEESP is still classified as a separate subject curriculum, which is a curriculum in which lecture/learning materials are presented separately between one subject and another (Sulaiman, 2013). In the context of STEM development, the separated subject curriculum pattern gives rise to separate STEM content in each course containing STEM content, as shown in Table 1. Likewise, the learning pattern is also carried out separately, and no integration between STEM subjects/content (Anggraini & Huzaifah, 2017; Roberts, 2012; Winarni et al., 2016) from various courses containing the STEM content. This is the cause of problems in STEM learning as referred to by Kurniawan et al. (2019), namely students' difficulty when using STEM content to solve problems in the ECD, which is caused by a lack of collaboration across STEM fields (Ejiwale, 2013).

The instructional curriculum at the MEESP is realized in SLP (Semester Lesson Plan) and LEU (Lesson Event Unit). The main components in the SLP are graduate learning achievement, course learning achievement, sub-course learning achievement, course descriptions, and learning resources. Meanwhile, LEU has main components such as SLP plus a learning experience component separated into offline and online and an assessment component. Based on the various components of the SLP, the opportunity for integrating STEM content is in the course description component, which is essentially the same as that found in the formal curriculum. While in LEU, the integration can occur in the learning experience component by describing the relationship between various STEM learning experiences and engineering construction design tasks.

Learning Patterns for STEM Subjects to Support Improving the Quality of Students' ECD

The separated subject curriculum pattern in the formal curriculum of the 2020 MEESP will give birth to a different STEM learning pattern. To produce meaningful STEM learning in supporting the improved quality of ECD, most of the lecturers (78.57%) agreed that there must be an effort to contextualize the STEAM content material with part of the ECD tasks, that is contextually appropriate. In this context, most of the lecturers (85.71%) agreed that the integration could be done by implementing learning/lecturing using the Problem-Based Learning (PBL) model where the "problems" presented to students were always associated with the part of the ECD tasks.

Through the FGD forum, it was agreed that selecting and using various learning models for a lecture is the prerogative of every lecturer. There should be no intervention by any party on selecting and using various models/strategies by each lecturer because those who understand the substance and what they want to achieve in their learning are the lecturers concerned. In this context, it was agreed that there was a need for a policy from the Head of the Mechanical Engineering Department or the Head of the MEESP related to various efforts to improve the quality of learning, including the use of PBL models to contextualize STEM content with ECD tasks. The learning pattern of the PBL model can be made in two ways, namely the presentation of problems at the beginning of the lecture related to ECD tasks and/or the presentation of STEM content application tasks associated with ECD tasks. There was excellent input during the FGD, namely (1) it is necessary to think about the possibility of making ECD task themes for every certain period (e.g. annually or biennially) that can be used to direct the integration of STEM content with ECD tasks in each course containing STEM content and on ECD tasks, and (2) the need for an emphasis on the Basic Mechanical Construction Design Course to direct each student to find topics or problems of ECD that can be proposed for the assignment of the ECDC.

Development of the Implementation of the ECDC

Various other findings related to the implementation of the ECDC in the MEESP are (1) most of the lecturers (78.57%) agree that every student taking the ECDC is required to make a proposal of SCP as stipulated in the curriculum of the 2020 MEESP, (2) more than half of the lecturers (57.14%) agree that the work on an ECD title is carried out by involving students across study programs, and (3) most of the lecturers (71.43%) agree that if the ECD is done by a team that involves students from other study programs must be guided by two supervisors, one of which is from another study program according to the origin of the student.

Making a proposal of SCP is one of the ECDC materials as contained in the 2020 MEESP Curriculum. The Head of the Mechanical Engineering Department explained that the basis for determining the SCP proposal was solely to increase the quantity of SCP proposal in Faculty of Engineering, which was the aspiration of the Vice Dean III. Therefore, making a SCP proposal is not an obligation/requirement of ECDC program. Therefore, although some lecturers (64, 29%) agree that the SCP proposal is one of the requirements that must be met by students when submitting an examination of the ECD report, the Head of the Mechanical Engineering Department stated that it should be reconsidered so as not to be burdensome and make the processing time for the ECD even longer. Regarding the involvement of students across study programs in working on the task of designing Engineering construction, the FGD forum agreed that (1) the involvement can be informal, namely asking students who are designing engineering construction to find discussion partners from students across study programs following the problems to be solved, or (2) involving students across study programs formally regulated in academic regulations so that they can be used as guidelines for the implementation of mentoring and recognition of student learning outcomes.

CONCLUSION

Based on the research and discussion results, it can be concluded as follows. First, it was identified that there were 15 scientific and expertise courses in the 2020 MEESP Curriculum containing STEM that supported the completion of engineering construction design tasks, namely the science content covering engineering physics, engineering chemistry, and material mechanics courses; technology content includes engineering drawing, engineering construction drawing, CAD, engineering assembling and installation, energy conversion, and mechatronics; engineering content includes materials mechanics, fluid and thermal, engineering statics and dynamics, and Machine Elements; mathematics content in the form of engineering mathematics course; and STEM content in the form of basic engineering construction design course. Identification of the STEM content of the various courses is shown in Table 2. Second, the integration of STEM content into the 2020 MEESP Formal Curriculum with a separated subject curriculum pattern contained in each course separately except for the basic construction design course that already integrates various STEM content. Courses containing STEM content are presented based on semester learning loads and scientific hierarchies, most of which are presented before the fifth semester except for the mechatronics course presented in the fifth semester and the engineering construction design course. In the instructional curriculum, the integration of STEM content in SLP is found in course descriptions, while in LEU it is found in the formulation of student learning experiences. Third, the meaningfulness of integrating STEM content to support engineering construction design can be done through the implementation of problem-based learning models in STEM-loaded courses by developing problems related to engineering construction design tasks, and/or making engineering construction design tasks as a problem that students have to solve using STEM content.

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