Developed concept and approach of Engineering Design course in the Fourth Industrial Revolution (IR 4.0): A study case in Mechanical Engineering

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Abstract

Increasing demand for practical and applied engineering courses to respond to the global-wide market has occurred in the latest decade. The influence of the Fourth Industrial Revolution (IR 4.0) changes the behaviors of government, university, and industry, which need a human resource with a complete skill-set, e.g., designing mechanical and engineering subjects. To achieve such purpose, sustainable teaching and education for bachelor students are required to be implemented. This work is presented to discuss taken efforts by Professors and Industry in the Department of Mechanical Engineering, Universitas Sebelas Maret to deliver the sustainable concept in the Engineering Design course. Collaboration with DTECH-Engineering, a design-engineering company, is manifested by involving a Chief of Executive Officer (CEO) in lectures, especially in delivering marketing and commercialization to the design approach. The students must attend classes and develop a design based on the assigned theme/topic. A series of assessment rubrics are presented to evaluate overall student performance based on the course's designed learning forms and criteria.

Keywords
Engineering design, mechanical engineering, collaborative teaching, industrial lecturer, and design dissemination

1. Introduction

Sustainable education is a must, not only at the macro-scale level, e.g., junior-high and senior-high schools to be continued to university, but also at the micro-level as found in the curriculum. The effort to keep continuity in transferring numbers of subject materials is taken as the market demand for human resources increases due to global challenges and rivalry. Transformation of industrial shape to be 4.0 mode is one of the motives. The biggest differentiator in Industry 4.0 (Yavas et al., 2020; Vinitha et al., 2020; Leong et al., 2020) is how stakeholders integrate technologies and relate them unprecedentedly. One system can communicate transparently with another, offering integration and decision support. It is necessary to create intelligently, connected, and capable factories of self-management to revolutionize manufacturing industries. To reach this purpose, especially in mechanical engineering (Pérez et al., 2019; Humbeck et al., 2021; Stechert, 2021), students are necessary to learn how to integrate cores of several courses to develop specific profiles which able to solve problems as mechanical engineers, e.g., in terms of mechanical design. To reach the designated profile, several integrated courses are composed. In Department of Mechanical Engineering, Univesitas Sebelas Maret (UNS) itself, at least three courses are involved, i.e., Machine Drawing, Engineering Design, and Engineering Manufacture/Project. Identification of course concept and approach is necessary work as the sustainability of the learning process (Hein et al., 2020; Zakariya et al., 2020) to reach engineer profile is vital

This work aims to identify the concept of involved course that shapes the engineer profile related to mechanical design, i.e., the course of Engineering Design. The approach used in this course is elaborated with several evaluations on examination data of student performance accounting for the design project. Partnership and collaboration with professionals in giving lectures and assessment to the student activity are later discussed as part of the course approach. Statistical results based on assignment and examination to the first student design version are presented as data for concluding the performance evaluation.

2. Course Profile

The course is entitled Engineering Design with the identification code MS68205-20 in the group of comprehensive skill code eight based on the latest curriculum document of the Department of Mechanical Engineering, UNS (later mentioned as ME-UNS) (Raharjo et al., 2020). The curriculum is composed to fulfill designated Graduate Profile and Description of the department, i.e., ***Engineer*** - Bachelor of Mechanical Engineering who can analyze and design mechanical systems (mechanics, energy, materials and manufacturing) and contribute to solving complex engineering problems; ***Technopreneur*** - Bachelor of Mechanical Engineering who has the ability in the fields of entrepreneurship, leadership and management to generate innovation and/or technology-based business; and ***Scientist*** - Bachelor of Mechanical Engineering who has the basic ability to research, transfer, and develop mechanical engineering sciences formally, informally and/or non-formally.

This course has value of 2 credits which is given in the third year with materials and subjects are including as follows:

- Design requirement and objectives / DRO (Identification of needs or problems, realistic boundaries, design requirements);
- Conceptual design (Development and evaluation of several concepts alternative);
- Detailed design (detailed design of each component and manufacturing process);
- Engineering analysis (analysis of existing forces and stresses and selection of engineering materials);
- Design for Manufacturing,
- Design for Assembly, Design for Safety; Engineering drawings (engineering drawings and manufacturing process drawings);
- The task to design a product or tool.

Learning outcomes of this work are planned to include five items, i.e., be able to show renewal design regarding science and cutting-edge technology (S3); be able to show attitude team up through the design process, discussion, and presentation (S4); be able of designing inner products mechanical engineering by correct design methods without leave out the aspect non-technical consideration (K5); be able to explain the design steps of a mechanical product in a coherent and systematic manner according to the correct design rules (P2); and be able to make scientific reports correctly and adequately orally and in writing in open and/or limited forums (P4).

3. Teaching Collaboration

The course is led by collaboration of two professors from ME-UNS, i.e., Aditya Rio Prabowo, Dr.Eng. (Assistant Professor) and Ubaidillah, Ph.D. (Associate Professor), and one professional from engineering design and manufacture company, i.e., Fajar Budi Laksono (CEO of DTECH-Engineering). In technical class, professors handle class administration and reliability analysis, such as house of quality (HOQ) estimation (Chen et al., 2017; Oddershede et al., 2019; Fang et al., 2021); and lecture regarding engineering design and manufacture (Doellken et al., 2021; Haq et al., 2021; Li et al., 2021); while professional introduces perspective of market point-of-view and product commercialization (Wagner and Wakeman, 2016; Su and Lin, 2018; Moaniba, 2020). Specifically, there are two classes are dedicated to engineering design and manufacture, two classes for product commercialization, and one class for HOQ analysis. Seven classes are used for students to perform the design process with teaching assistants are provided in this stage. To provide real-world application, the design will be submitted for a competition. In this case, students have to fulfill all competition requirements besides the technical drawing and design. Furthermore, final evaluation by professors and professionals will conclude which design will be submitted to a different class of intellectual property rights.

4. Subject and Project

The course is addressed to enhance student skills in terms of engineering design. A series of parameters is set to ensure such skills are obtained (see Table 1 for details). To evaluate student skills based on those parameters, it is needed to define each learning form to specific tasks and projects in the course. As the first, the Assignment, which has a maximum score of 10, the student is required to make a summary based on material delivered by each lecturer. The summary is set to include manufacture, commercialization, and reliability materials. The score for each summary/resume will be averaged to be taken as the final score for this learning form. Second, the Report, which has a maximum value of 35, is directed to evaluate students' designs in the middle exam. In this stage, students in the group are required to present their background, calculation, and preliminary design of a given project theme. Third, the Product Display, which has maximum value of 20, is arranged to evaluate the composed video and final student design report. Fourth, the Poster and Presentation, which has a maximum value of 15, is an evaluation medium for student presentation in describing their works. Therefore, PowerPoint presentation and Q&A section will be the main focus of this learning form. Fifth, Team Work, which has a maximum value of 20, is the final parameter to ensure the student is working well in their group. In this task, each student in a group is given an exclusive right to provide the score to other members. The final score for this learning form is taken based on the sum of the given scores.

Table 1. Criteria for each learning form in the Engineering Design course.

Leaning Form	Criteria
Assignment (Before mid-exam)	Able to demonstrate the up-to-date design by referring to the latest science and technology [C1].
Report (Mid-exam)	• Able to design products in the field of mechanical engineering with the correct design method without leaving the consideration of non-technical aspects [C3]. • Able to explain the steps of designing a mechanical product coherently and systematically according to the correct design rules [C4]. • Able to make scientific reports correctly and adequately orally and in writing in open and/or limited forums [C5].
Product display (Final exam)	Able to explain the steps of designing a mechanical product coherently and systematically according to the correct design rules [C4].
Poster and presentation (Final exam)	Able to make scientific reports correctly and adequately orally and in writing in open and/or limited forums [C5].
Teamwork (Final exam)	Able to demonstrate the attitude of working together in a team through the process of design, discussion, and presentation [C2].

At the end of the semester, before the final exam, the students are instructed to submit their design idea and innovative design to a competition entitled Indonesia Good Design Selection (IGDS) 2021 held by the Ministry of Industry, Republic of Indonesia. Besides wellness of design in scientific aspect, students have to promote commercial point-of-view of their design. This stage is also considered in this course so that in student mindset, the design or future design they make will also be valuable in terms of business and commercial terms. The registration form/evidence for this competition needs to be conveyed to lecturers through assistants as part of the requirement to participate in the final exam.

5. Performance Evaluation

The students will be evaluated based on the composed assessment rubric according to each learning form as discussed in the prior section. The assignment will be checked based on the delivery skill of the students in writing the summary of lectures (see Table 2). The report in the second learning form will be evaluated based on three criteria, i.e., C3, C4, and C5. The set parameters to evaluate the criteria are displayed in Tables 3 and 4. The product display will be checked based on the presented rubric in Table 5, which focuses on the video and final reports of the design project. The poster and presentation in the following learning form are also evaluated using the rubric as presented in Table 4, which focuses on the PowerPoint presentation and question-and-answer session. Finally, the teamwork aspect is evaluated using composed indicators in Table 6, which is mainly directed toward member performance in completing the project.

Table 2. Assessment rubric: assignment - C1

Grade	Score	Indicator
Excellent	10	Organized by presenting the final answer supported by work that has been analyzed according to the concept
Very good	8 - 9.9	Well organized and present convincing answers to support the conclusion/final answer
Good	6 - 7.9	The article has a focus and presents some evidence of the workflow that supports the final conclusion/answer
Acceptable	4.5 - 5.9	Focused enough, but writing is insufficient to be used in drawing conclusions/final answers
Not good	3 - 4.4	Lack of clear organization in writing. The working method/method described in the presentation is not used to support the final conclusion/answer.
Poor	1.5 - 2.9	Lack of clear organization in writing. Writing does not describe the material.
Unacceptable	< 1.5	Does not give the answers.

Table 3. Assessment rubric: report – C3

Grade	Score	Indicator
Excellent	15	The presented design is systematic, problem solving, can be implemented and innovative.
Very good	13 -14.9	The presented design is systematic, solves problems, can be implemented, but is less innovative.
Good	10 - 12.9	The presented design is systematic, solves problems, but cannot be implemented.
Acceptable	7 - 9.9	The presented design is systematic but rarely solves the problem.
Not good	5 - 6.9	The presented design is systematic but does not solve the problem.
Poor	3 - 4.9	The presented design is less systematic.
Unacceptable	< 3	The presented design is irregular and does not solve the problem.

Table 4. Assessment rubric: report – C4 and C5; and poster and presentation – C5

Grade	Score	Indicator
Excellent	15	Presentation (in PPT or Q&A) organized by presenting presentations and final answers supported by work that has been analyzed according to the concept
Very good	13 -14.9	The presentation (in PPT or Q&A) is well organized and presents a convincing presentation and answer but without analysis to support the final conclusion/answer
Good	10 - 12.9	The presentation (in PPT or Q&A) has a focus and presents some evidence of the workflow that supports the final conclusion/answer
Acceptable	7 - 9.9	The presentation (in PPT or Q&A) is presented systematically but rarely solves or answers the problem
Not good	5 - 6.9	The presentation (in PPT or Q&A) is quite focused, but the evidence on the presentation is insufficient to be used in drawing conclusions/final answers
Poor	3 - 4.9	The presentation (in PPT or Q&A) is not clearly structured. The working method is not used to support the final conclusion/answer.
Unacceptable	< 3	Exposure (in PPT or Q&A) does not show results and provides answers

Table 5. Assessment rubric: product display – C4

Grade	Score	Indicator
Excellent	20	The presented design (in video or final report) is systematic, problem solving, can be implemented, and innovative.
Very good	16 -19.9	The presented design (in video or final report) is systematic, solves problems, can be implemented, but is less innovative.
Good	12 - 15.9	The presented design (in video or final report) is systematic, solves problems, but cannot be implemented.
Acceptable	9 - 11.9	The presented design (in video or final report) is systematic but rarely solves the problem.
Not good	6 - 8.9	The presented design (in video or final report) is systematic but does not solve the problem.
Poor	3 - 5.9	The presented design (in video or final report) is less systematic.
Unacceptable	< 3	The presented design (in video or final report) is irregular and does not solve the problem.

Table 6. Assessment rubric: team work – C2

Grade	Score	Indicator
Excellent	20	Members are involved in every work process and play an active role in decision-making, including presenting ideas and solutions.
Very good	16 -19.9	Members are involved in every work process but play a passive role in decision-making.
Good	12 - 15.9	Members are involved in the work process and occasionally do not meet the specified deadlines/targets
Acceptable	9 - 11.9	Members are not involved in the work process directly/explicitly
Not good	6 - 8.9	Members are not involved in the work process directly/explicitly and hinder the group's progress
Poor	3 - 5.9	Members are not involved in the work process but attend lectures
Unacceptable	< 3	Members are not involved and withdraw from the group

6. Concluding Remarks

The paper is addressed to present a course profile matched with industry and market demand in the era of Industrial Revolution (I.R.) 4.0. Engineering Design of ME-UNS is a collaborative course that professors and professionals handle separately specific materials but are still in line to make students enhance their mechanical engineering and design skills. The material scopes include manufacture, reliability, and commercialization of the design/product. A series of learning forms are given to students, including a challenge to submit their design into a nationwide competition to give real-world experience in market interaction and product promotion. Based on the breakdown of the course, Engineering Design is indeed a complex course that requires sustainability improvement, especially in terms of reading market demand. The engineered design needs both to be working and to be accepted by society in a commercial sense. This effort is projecting the student to capable as engineer and entrepreneur in future or post-graduation, which will impact the national economy and job opportunity.

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Biographies

Aditya Rio Prabowo, Dr.Eng. interests in accident-related phenomena in marine environment, including collision, grounding and explosion. The scope of his work also concerns extreme regions for engineering operations, such as Arctic Engineering and Polar Sciences. His research is dedicated to investigating the structural crashworthiness of marine structure, including ships and containers. Besides these subjects, he directs the research work to ship design for the special purpose, propulsion performance, clean energy instrument, and computational modeling and analysis. Most of the researches is presented in international symposiums and conferences, i.e., OMAE organized by the American Society of Mechanical Engineers (ASME), EMI organized by the American Society of Mechanical Engineers (ASCE), and ICSI presented by European Structural Integrity Society (ESIS).

Ubaidillah, Ph.D. research has focused on magnetorheology since 2007. Many works have been conducted, from materials development to the device application based on Magnetorheological Plastomer. Numbers of industrial prototypes, such as semi-active suspension, are currently developed with Kabaya Indonesia. Furthermore, Ubaidillah also has been researching acoustic materials since 2015. Several articles have been published in the area of acoustic materials.

Fajar Budi Laksono, M.Eng. and DTECH-ENGINEERING win global competition such as the 1st Place on the GE & Fuse - On Wing Jet Engine Inspection Design Global Competition (2017). In the GE & Fuse - On Wing Jet Engine

Inspection Design Global Competition, they are solving the "almost impossible" problem to upgrade an on wing jet engine inspection device to increase the safety and efficiency of commercial aircraft. They combine intelligent automation devices, big data, and artificial intelligence to get things done easier and faster.