The essential of engineering education involving critical thinking and problems solving skills among mechanical engineer employees

W Omar Ali Saifuddin Wan Ismail¹*, Noraini Hamzah², Ireana Yusra Abdul Fatah¹, and Azry Khoiry Muhammad²

¹Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Terengganu, Malaysia
²Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia.
*Email: woasaifuddin@unisza.edu.my

Abstract. Engineering Education is a course that emphasis on soft skills that are related to critical thinking and the ability in solving problems. Creative and Critical Thinking Skills (CCTS) is a type of skill that had introduced and strongly emphasized in the education system, starting from primary school. Recently, all the exam questions in primary, secondary schools and public universities oriented to the principle of Higher Order Thinking Skills (HOTS) in (RMK 11 - Transforming Education System). The objective of this education program is to produce students that are more competent in solving problems by applying effectively various forms of knowledge that had studied theoretically. This study aims to examine the extent to which the needs of elements of critical thinking and problem-solving skills to produce competitive engineers from industries point of view. Feedback from respondents was taken through quantitative methods using a set of questionnaires. A total of 300 respondents have participated in this study. The study is expected to be a guide for future mechanical engineers who would be involved by the requirements of the mainstream industry.

1. Introduction
In the 19th century, critical thinking referred to the ability to analyse information, determine the relevance of the data collected and interpreted in solving the problem [1-5]. By the 20th century, critical thinking consists of things that show our thoughts by thinking of the activities we do [6] in a higher-level (High Level Thinking skills) which involves the process of analysis, valuation, fairness, and reflection [7,8]. Critical thinking also helps in the cognitive development of students when they try to collect as much information as possible to solve problems, organise information, and to look at the issue from a different perspective [9,10]. Critical thinking involves the purposeful, goal-directed thinking during the process of making decisions based on the evidence in the scientific problem-solving process and not just a mere guesses [11,12]. Through the development of this ideology, critical thinking and judgment method are required for engineers at a professional level to solve the big part of the problems at work [13], and it is part of the requirements for getting a good job in the engineering field in particular. [14-16].

The process of problem-solving is an essential requirement for any engineer [17], and it is significant for all other professional position [18]. Therefore, the need to foster a tendency to think critically viewed as an essential component in the development of the thinking process and the approach to problem-solving that forms into expertise [19]. Focusing on problem-solving skills have been disclosed at all
levels of education particularly at the Higher Learning Institute, but the results of the study showed that the ideology of engineering students to solve problems are at low levels despite the various efforts that had been carried out by the trainers in the four-year bachelor's degree program [20]. Engineering students are thinkers who need more critical thinking than students in the social sciences, basic sciences and humanitarian courses [21-23].

The need for critical thinking and problem-solving skills will continue to increase in years to come, given the urgent need for new insights about the ways of people handling complexity and uncertainty [24]. Implementation of the i-think program began in 2014 as a thinking tool to catalyse high-level thinking to enhance and cultivate thinking skills among students [25]. All employers and the organisation in the industry is trying to employ and train engineers of all disciplines based on the problem-solving and critical thinking skills with the combination of communication skills [26, 27].

2. Experimental

Discriminant Analysis Method was used to process the data. A total of 300 respondents were involved in answering these questions. All the respondents from the industry consist of management and administration groups, senior engineers, senior technologist, and engineers. Items of the issues show the extent to which the requirements for Critical Thinking and Problem-Solving Skills element according to current industry needs. Through this sum then comes the reading percentage and mean for Critical Thinking and Problem-Solving Skills element with values in the table.

2.1 The Model Soft Skills Higher Education Institute

According to figure 1, Model Elements of Soft Skills has been introduced by the Ministry of Education (MoE) Malaysia and has become the primary source of success and outcomes for the students at a certain level.

![Soft Skills Model](image)

**Figure 1.** Soft skills model (MoHE).

Throughout this study, the researchers have used this model, which consist of seven elements where one of the important highlighted factors listed was the Critical Thinking and Problem-Solving Skills. Later will represent the importance of applying thinking skills among students in both public and private universities apart from their earlier education. Since reforms in education are focusing on critical thinking process including the item solving problem [28-30] as a cognitive starting point [31], the development progress continues for a positive impact towards the employment environment.

Model of Formation of First Class Mentality has been wrought by the Ministry of Education (MOE) Malaysia as shown in figure 2.
The composition of the importance and the need has been clearly in the thinking skills competency model. The Think Element was thought to be a fundamental part of every stage of the process known as creative and critical thinking in achieving the ultimate goal of engineering education at universities. Criteria contained in this model detailed in the construction of the questionnaire. Each level emphasises the importance of thinking skills variously in problem-solving and decision making.

Currently, the ability and availability to identify and problem-solving among engineering students in Malaysia are highly required. This essential element in the practice of critical thinking is the practice of reflection [32] which will assist the individual vital and analytical thinking in solving any problem and methods to develop a positive attitude towards addressing all of the issues [33]. In applying critical thinking, students need to explore creativity by defining the problems using one of the common creative tools (5w+1h - what, who, where, when, why and how) to identify the problem and solve them [34] with distinction variety of solutions.

Today's scenario, graduates had face problems in getting jobs due to their lack of critical thinking ability other than knowledge and soft skills performance [35]. Measures for the better idea is to provide a model for teaching and assessment following the criteria in Higher Order Thinking Skills (HOTS) openly to encourage students to use creative and critical thinking skills in problem-solving [36, 37]. Engineering students not only need to have the qualifications and technical skills to manage their role in carrying out daily work but, without the soft skills, employers are less likely to make these graduates as workers in their organization at a professional level, managers or even business partners [38]. Focusing through a modern engineering student, soft or generic skills is an element that must be mastered and blended in each skill aspect if they want to carry out the work successfully at the same time, help improve the ability and development of the company [39, 40].

3. Results and discussions

3.1 Descriptive Statistics Demographics Analysis
Table 1 shows the histogram of the current position of respondents and descriptive statistics demographics have work experience of more than five years in the industry, especially in the mechanical engineering field and department of engineering. Five years of working experience was suppose known to be the starting point for the maturity period in career path.

| Figure 2. Model of formation of the first class mentality. |
|----------------------------------------------------------|

Table 1. Descriptive statistics demographics.
Table 2 shows the histogram gender of respondents and descriptive statistics demographics with the number of respondents noted. 240 were men and 60 women. It involves staff in heavy (HICOM), medium and small (SME) industries throughout the peninsular of Malaysia. Generally, the majority staff in the mechanical engineering field led by male.

Table 2. Descriptive statistics demographics.

| No. | Gender | Frequency | Percentage |
|-----|--------|-----------|------------|
| 1   | Man    | 240       | 80.00      |
| 2   | Woman  | 60        | 20.00      |

3.2 The Findings of Seven Items in Questionnaire

The questionnaires were distributed to the respondents for the constructive answer and respond. The sets of selected questions that have risen in the questionnaire are as follows table 3.

Table 3. Items of the questionnaire.

| Questions | Item Questions |
|-----------|----------------|
| Q1        | Ability to identify and problem analysis in a complex and ambiguous situation and make justified evaluations. |
| Q2        | Ability to expand and improve thinking skills such as explaining, analysing and evaluating the discussion. |
| Q3        | Ability to search for ideas and find alternative solutions. |
| Q4        | Ability to think outside the box. |
| Q5        | Ability to make decisions based on strong evidence. |
| Q6        | Ability to persevere and give its full responsibilities assigned. |
| Q7        | Ability to understand and adapt to the culture of the community and a new work environment. |

Table 4 shows the findings of the seven-item questionnaire involved in this study. Based on the results, all questions are at a very high level of need. Surprisingly, for Q6, 100% of the respondents agreed that mechanical engineering students must have high resilience to face a variety of possibilities where they also need to be responsible for the trust that has an entrusted to them. Results for the Q5 found that 96% of respondents agreed that students in this field should be able to create an effect based on the authentic evidence. Meanwhile, 94% believe that mechanical engineering students should have the ability to identify and analyse any problem in any situation and develop their thinking skills for both
Q1 and Q2 respectively. They have to be smart in interpreting the assessment and elaborate a clear explanation or idea. This ability can be practised and applied during assessment and group discussions.

**Table 4.** The findings of the seven items questionnaire.

| Questions | Need Level | Percentage |
|-----------|------------|------------|
| Q1        | Very High  | 94.00      |
| Q2        | Very High  | 94.00      |
| Q3        | Very High  | 93.66      |
| Q4        | Very High  | 86.33      |
| Q5        | Very High  | 95.66      |
| Q6        | Very High  | 100.00     |
| Q7        | Very High  | 91.33      |

The findings for Q3 also showed that almost 94% of these mechanical engineers have to be smart in generating new ideas. They need to be more creative and aware with current issue/technology in generating new ideas as an alternative to complete the task. The resulting of 91% for Q7 shows that the students in the mechanical engineering stream have to be smart to face and adapt to any situation so that they understand the work culture despite being in a new place. Lastly, for Q4, the results showed that 86% of respondents agreed that thinking outside the box is important for every mechanical engineering student to ensure that any action taken is more matured and beyond limit expectation.

3.3 *Evaluation of Response from Questionnaires*

Table 5 shows the justification of percentage and the mean score used in this study. The researcher used the score mean: i. 3.68 - 5.00 (High Needs); ii. 2.34 - 3.67 (Medium Needs); and iii. 1.00 - 2.33 (Low Needs). This method is used to simplify the process of classifying the results.

**Table 5.** Classification mean requirement levels.

| Formula       | Mean       | Level | Justification |
|---------------|------------|-------|---------------|
| 5 - 1 / 3     | 3.68 - 5.00| Three | High          |
|               | 2.34 - 3.67| Two   | Medium        |
| 1.33          | 1.00 - 2.33| One   | Low           |

(Source: Modified from Likert Scale, 1932)

Figure 3 shows box plots of mean Critical Thinking and Problem-Solving Skills generated based on the questions that had been answered by the respondents. From figure 3, the information transferred into Table 6 and all the results clearly shown.
Figure 3. Box plots mean Critical Thinking and Problem Solving Skills.

Table 6 shows the mean and summary statistics of Critical Thinking and Problem-Solving Skills. From the results obtained, each respondent answered all the questionnaire with a minimum score at 3.00, and a maximum score at 5.00. Likewise, there is no respondent prefer to tick at the rating 1.00 and 2.00 for the entire questionnaire item. Items that had the highest mean value is Q3 (4.57), followed by Q6 (4.56), Q1 (4.52), Q7 (4.48), Q2 (4.47), Q5 (4.43) and the lowest mean value is item Q4 (4.28). It fulfilled the requirement and in line with Table 4, which accumulate the mean value of 3.68 - 5.00 at a high level. Therefore, the mean results interpreted those seven questions items are at a high level of need, and it also corroborated by Table 6 and references [28-31].

Table 6. Statistical summary Critical Thinking and Problem Solving Skills.

| Question Item | Respondent | Minimum | Maximum | Mean Item |
|---------------|------------|---------|---------|-----------|
| Q1            | 300        | 3.00    | 5.00    | 4.52      |
| Q2            | 300        | 3.00    | 5.00    | 4.47      |
| Q3            | 300        | 3.00    | 5.00    | 4.57      |
| Q4            | 300        | 3.00    | 5.00    | 4.28      |
| Q5            | 300        | 3.00    | 5.00    | 4.43      |
| Q6            | 300        | 4.00    | 5.00    | 4.56      |
| Q7            | 300        | 3.00    | 5.00    | 4.48      |

Based on the Descriptive Analysis (DA), the percentage of the overall reading with a view to the needed and very needed. The only two items show the need for any findings either high or low requirements of the industry in producing competitive mechanical engineers the percentage shown in table 7.

Table 7. Classification percentage of requirement level.

| Formula | Percentage | Level | Justification |
|---------|------------|-------|---------------|
| 80.6 - 100 | Five      | Very High |
| 100 - 1 / 5 | 60.7 - 80.5 | Four   | High         |
| 19.8    | 40.8 - 60.6 | Three  | Moderate      |
|         | 20.9 - 40.7 | Two    | Low          |
Figure 4 represents the item questions that are at high-level requirements. The horizontal axis represented a question answered by the respondent, and the vertical axis indicates the portion of the results of each item based on the percentage. The seven issues are at the high-level requirements, and it is also fulfilling the condition in table 7, which is the percentage value of 80.6 - 100.00 is the very high level. It gives the impression that the element of the Critical Thinking and Problem-Solving Skills are needed by engineering students, as mentioned in reference [18] and [33].

![Graph plot item question (Critical Thinking and Problem Solving Skills).](image)

Table 8 shows the percentage of the whole item question formulation of Critical Thinking and Problem Solving Skills. The percentage of 94% showed a very high level of requirements of demand for competitive Mechanical Engineers according to the current needs and industries. It must entirely have mastered before facing the real world according to a ref [39].

| Item | Need Level | Value  |
|------|------------|--------|
| Percentage | Very High | 93.57  |

Based on ref [38,40] generic skills are a guide for each engineer to assess the extent of their level of knowledge, skills and attitude towards engineering, but more than that, today the industry needs additional skills and one of them is critical thinking and problems solving abilities among engineers in Malaysia to compete with other countries around the globe.

3.4 Reinforcement of critical thinking component

In designing a firm professional engineer, many approaches and methodology be practiced in the engineering module at the university level that related to critical thinking components. There have five basic critical thinking components that are necessary can be implemented in the curricular university course for the Mechanical Engineering student. These components include specific knowledge, experience, competencies, attitude and professional standards. Blends of these five components will produce a competent engineering output as suggested in [41,42]. The particular content of an engineering education syllabus that involved written documentation as well as scoring rubric should revise according to critical thinking and problem-solving scope. During degree programme, engineering student must be able to demonstrate a representable, creative and rational presentation with a high critical thinking effect. While, in solving any kinds of problem, students must be able to explore several concepts simultaneously to reach a practical solution.
Under the Eleventh Malaysia Plan 2016 - 2020: A Roadmap (10.77), all the higher education institution are required to review the program regularly offered to drop the program that overlaps and is no longer relevant to the industry and provided no benefits. Continuous efforts to improve the quality and the introduction of the new program will be through review and rigorous screening to ensure that this program has a better curriculum, the added value that appropriate and meet the needs of the industry. Based on a study done by [42], critical thinking and problem-solving approached should be taught to various academic centres including both institutes, not only in public university but also private university that offers engineering courses.

An overview of the important element of thinking skills and problem-solving skills applied in the curriculum of engineering education had stressed in this particular study. Lacking skills of critical thinking and problem-solving among job applicants have commonly reported the essential skills deficit to 45% among job applicants based on the JobStreet.com website, and it is a worrying situation for the next-generation engineer.

4. Conclusions

In producing high potential mechanical engineering students to fulfil the gap of the current job market, the emphasis should be given on the elements of critical thinking and problem-solving skills. The item has become an interest and is no longer a requirement. Students in this area are advised not to only rely on their academic textbooks alone as this will limit their level of creative thinking. So, instructors and academicians must also act as facilitators in guiding and practising self-reflection processes which are essential elements in critical thinking and abandon chalk and talk teaching techniques. Research also proves this element of soft skills needed by the industry towards a positive and high qualified engineer. Mechanical Engineering environment is circulating and moving forward according to the rapid technological advancement, so it is not too much to say, graduates and engineers of Mechanical Engineering need to pay more attention in applying and exploring critical thinking in their future career endeavours. Therefore, competence in soft-skill is main criteria required by the industry in hiring skilled proficiency employees and holistic engineers.

References

[1] Gagne R 1988 Instructional Science. 17(4) 387-390
[2] Halpern DF 1989 Thought and knowledge: An introduction to critical thinking (Hillsdale, NJ: Lawrence Erlbaum)
[3] Ennis RH 1991 Goals for a critical thinking curriculum ed AL Costa
[4] Snyder LG and Snyder MJ 2008 Delta Pi Epsilon Journal L(2) 90-99
[5] Halpern DF 1998 American Psychologist 53(4) 449-455
[6] Dantas-Whitney M 2002 System 30(4) 543-555
[7] Jeevanantham LS 2005 Why teach critical thinking? Africa Education Review 2(1) 118-129
[8] William D, Hendricson MA, Sandra MS, Andrieu C, Chadwick DG, Jacqueline E, Chmar BA, James R, Cole, Mary C, George RDH, Gerald N, Glickman, Joel FJD, Glover, Jerold S, Goldberg, Haden NK, Cyril Meyerowitz, Neumann L, Pyle M, Lisa A, Tedesco, Richard W, Valachovic MPH, Richard G, Weaver, Ronald L, Winder, Young SK, Kenneth L and Kalkwuar 2006 J. Dental Education 70(9) 925-936
[9] Kathaplia SS and Heah C 2008 RELC J. 39 300-317
[10] Reinstein-Staton R 2008 The rights and wrongs of strategic planning’, security: for buyers of products, systems & services. 45(7) 34-36
[11] Nugent PM and Vitale BA 2008 Fundamental success: a course review applying critical thinking to test taking, USA: F. A. Davis Company
[12] Lau J 2012 A Mini Guide to Critical Thinking
[13] Stevens R, Johri A and O’Connor K 2014 Professional engineering work ed Johri A and Olds BM (Chapter 7: Cambridge handbook of engineering education research, Cambridge University Press, New York)
[14] Mohamad S, Rasul R, Annah AR and Mohd YH 2014 Kemahiran kebolehdapatan kerja suatu keperluan pekerjaan (Penerbit Universiti Kebangsaan Malaysia, Bangi)
[15] Kamarudin MT, Ruhizan MY and Ramlee M 2014 *Pemangkin kebolehpasaran graduan, status pekerjaan graduan*, 30 (Penerbit Universiti Kebangsaan Malaysia, Bangi)

[16] Mohd Huzairi J, Yuzainee MY, Mohd Zaidi O and Azami Z 2014 *Kemahiran kebolehgajian graduan kejuruteraan* (Penerbit Universiti Kebangsaan Malaysia, Bangi)

[17] Aldridge MD 1994 *J. Eng. Education* 83(3) 231-236

[18] Eraut M 1994 *Developing professional knowledge and competence* (Falmer Press, London)

[19] Walker SE 2003 *J. Athletic Training* 38(3) 263-267

[20] Nickerson RS 1994 *The teaching of thinking and problem-solving* ed Sternberg RJ *Thinking and problem-solving* (2nd ed. San Diego: Academic Press)

[21] Leach BT and Good DW 2011 *Int. J. Humanities and Social Science* 1(21) 100-106

[22] Aliakbari M and Sadeghdaghighi A 2011 Investigation of the relationship between gender, field of study, and critical thinking skill: the case of Iranian students. *Paper Presented at The 16th Conference of Pan-Pacific Association of Applied Linguistics*, The Chinese University of Hong Kong 301-310

[23] Mahdyeh N and Arefi MA 2014 *Indian J. Fundamental and Applied Life Sciences* 4(1) 153-162

[24] Funke J 2013 *J. Problem Solving* 6(1) 2-19

[25] Hasnah I and Jamaludin B 2017 *Malay Language Education J.* 7(1) 56-65

[26] Vanderbilt University School of Engineering

[27] Rosdiadee N 2013 *Technical communication skills among recent electrical and electronics engineering graduates in job industries* 164 (Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia)

[28] Pusat Perkembangan Kurikulum 2002 *Kemahiran berfikir dalam pengajaran dan pembelajaran* (Pusat Perkembangan Kurikulum, Kementerian Pendidikan Malaysia)

[29] Bahagian Jaminan Kualiti 2004 *Panduan kriteria dan standard bagi program bidang pendidikan* (Jabatan Pendidikan Tinggi, Kementerian Pendidikan Malaysia)

[30] Roselainy AR, Yudariah MY, Hamidreza K and Sabariah B 2012 *Developing mathematical communication skills of engineering students* (Procedia-Social and Behavioral Science)

[31] Collins JP 2008 *Modern approaches to teaching and learning anatomy*. Student BMJ 337:a1753

[32] Colley BM, Bilics AR and Lerch CM 2012 *The Canadian J. for the Scholarship of Teaching and Learning* 3(1) 1-19

[33] Jake M and Laguador 2013 *Developing students’ attitude leading towards a life-changing Career* (Educational research international)

[34] Infor Resources System Sdn. Bhd. 2001 *Creativity and creative problem-solving* (IRRSSB Selangor)

[35] Ili Atiqah Md D and Ruslin A 2016 *J. Psikologi Malaysia* 30(1) 16, http://www.wolcottlynch.com

[36] Campos HM, Rubio AM, Atondo GH, Palma YM and Chorres 2015 *Relationship between creativity, personality, and entrepreneurship: An exploratory study* (Mexico)

[37] Mishra DS 2016 *Int. Research J. Eng. and Tech.* 3(2)

[38] Inayatullah K, Noor Abidah MO, Yusuf B and Zafar Iqbal SM 2012 *Int. J. Applied Linguistics & English Literature* 1(5) 176-183

[39] Anderson C and John FG 2013 *Skills requirement for tomorrow’s best jobs helping educators provide students with skills and tools they need* (IDC Analyse the Future)

[40] Desmond A and Martin J 2016 *Int. J. Higher Education* 5(2) 23-59

[41] Hairuzila I, Hazadiah MD and Normah A 2010 *2nd Int. Congress on Engineering Education*, Kuala Lumpur, Malaysia 258-263

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