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Research Article

Maker Smart Education: Methodology and Technologies to Train New Engineers in Line with Industry 4.0

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Abstract

The fourth industrial revolution has been changing the way of working, social relations and learning. Training an engineer today demands that the courses be adapted to offer what industry and society expect from new professionals. In this sense, the Research Group I4.0 of the Universidade Paulista is working within a model proposed (termed as Maker Smart Education), which is composed of the integration of three teaching approaches with laboratories/technologies and methodologies to reinforce concepts. The development of the model emerges from the conjunction of the experience of four decades of training engineers, teaching specialists opinions, bibliographic research and dissertation results. The integration of approaches, techniques inclusion and adoption of methodologies that compose the model arises from a dynamic evolution that also depends on industrial needs' feedback. In this way, a survey was conducted among industrial specialists who collaborate with the university on various research topics, aiming to obtain feedback on the techniques and methodologies just implemented or under implementation at the university. The feedback is a way to maintain the improvement cycle and the coherence with industrial demands. The survey showed an adequate level of agreement of the professionals with the supporting technologies and methodologies adopted. Surveys have been proved to be a useful tool for continuous improvement.

Keywords: Engineering education, industry 4.0, 3D printing

1. Introduction

Industry 4.0 (I4.0) that is improving the industrial processes and changing the global market and the whole society due to the adoption and integration of new technologies, is also creating challenges for the formation of future engineers.

The I4.0 is based on the integration of information and communication technologies and industrial technology. It is mainly depends on building a cyberphysical system to realize a digital and intelligent factory, and promote manufacturing to become more digital, information-led, tailored, and green [1]. The new Engineers need to adapt quickly to the novel demands of industries in the context of I4.0. Moreover, it is expected that the demands of modern industry contexts will reshape the working world of future engineers, according Terkowsky, Frye and May (2019) [2]. In the face of this reality, the university plays a relevant role by adapting curricular content and promoting new technologies to enable graduate engineers to acquire the necessary competencies. However, to select the appropriate curricula, its structure, content, class dynamics and technologies are not accessible.

When equipment can communicate, exchange information and act, diverse aspects of every day and work environment, need to be adapted. It is expected that universities and academicians should weigh their knowledge and abilities to update and advance themselves to future generation [3].

The educational administrators are responsible for changing the Engineering course curricula to ensure graduates will acquire the competencies to work with Industry 4.0 and consequently ensure employment for these new professionals. It is expected that the early contact still in graduation with these technologies will improve professional skills to deal with the new paradigm of I4.0. Thus, academic institutions need to focus on the design and development of educational programs based on innovative teaching techniques [4].

Zin (2015) [5] discusses how the technical education can be adapted according to requirements of the Industry 4.0 and Coskun, Kayikci and Gençai (2019) [6] proposed a generic framework for Industry 4.0 education that consisted of curriculum, laboratory, and student club components to adapt engineering education to the Industry 4.0 vision. For this reason, the new technology trends (virtual learning environment, learning factory, or augmented reality) should be included in education [4].

The fundamental mission of universities includes three main functions: professional training to face technological, social, politics and economic challenges; creation of knowledge through scientific research, and contribution to quality of life improvement through knowledge sharing [7]. Moreover, integration of those main functions could result in positive feedback to the attainment of the outputs. The combination of undergraduate level necessities, the identification and fulfillment of the new professional requirements, and the expertise of postgraduate staff could result in innovative ways of facing the challenges relating to curricula adaptation. We are convinced that the research groups, more usually linked to master and doctoral degrees, should interact with undergraduate courses to develop and suggest new infrastructure and equipment to prepare students in line with new requirements. In this context, the Industry 4.0

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research team at Universidade Paulista (UNIP) is aiding in developing a teaching-learning model that was termed MsE (Maker Smart Education), devoted to training engineering students who will work with new technologies and concepts.

The selection of the technologies supports the model carried out with the contribution of a group of specialists in engineering education [10]. Some of these technologies are currently being implemented at the university.

However, it is essential to complete or even validate the selection through the relevance that these technologies have in the industry and how their knowledge and familiarity in graduation would contribute to acquiring of skills in young professionals. That is, to validate technologies that, if included during undergraduate teaching-learning processes, will help to obtain the "industry desired" skills. According to Araújo et al. (2019) [8] the skills needed by engineers in order to succeed in industrial practice have already been presented in several studies and, engineering communities have been struggling for more than a decade with the issue of soft skills development [9]. There is a plethora of evidence indicating an urgent need for engineers to improve their soft skills [9].

This work aims to promote feedback from the industry experts about the technologies that support the MsE (Maker Smart Education) and know their opinion about their effectiveness for helping students be inserted in these concepts and ensure graduates' employability. Since the teaching learning model is not static but dynamic, the feedback is a way to maintain the improvement cycle and the coherence with industrial demands. To accomplish this goal, a group of industrial experts were subjected to a survey composed of questions with 5-level Likert format made in Microsoft Forms sent by e-mail. These industrial specialists are engineers, technologists and technicians working in the modern industry and usually assist in university research. It is expected that potential employers' feedback, who knows companies' demands, will add to tailor the academic and research curricula at universities to be in line with the digital transformation and the implementation of I4.0 strategies.

As a secondary objective of this paper, the statistical treatment of the questionnaire's data on the Likert scale is also briefly discussed.

2. MsE model

Preliminary studies that resulted in the paper titled "Industry 4.0: Teaching model for training Production Engineers" [10] introduces the model proposed, which was developed by the support of bibliographic research, surveys to know the opinion of teaching specialists, and the experience of most than four decades in engineers training. The teaching specialists were subjected to a Likert-scale questionnaire using a Delphi specialist method to reach a consensus. The resultant model can be explained by integrating three approaches as shown in fig. 1. A schematic illustration of the model is displayed as the intersection of the three circles representing the integration approaches. The MsE is assisted by infrastructure (shown as Fablab, VR and I4.0 Lab in fig. 1) concerned with the disruptive technologies of the I4.0 (see next Section 2.1) that were supported through the specialists' opinion [10].

First, it is essential to explain the name of the model (MsE). The Maker education is constructed by the constructivism and constructionism movements, where the students drive multidisciplinary experiences that allow them to develop diverse skills. According to Peterson (2012) [11] in constructivism, the passive observer's notion is abandoned, and the students are encouraged to place and test new hypotheses to respond to new situations. Mackrell and Pratt (2017) [12] indicated that Piaget's idea is that the apprentice builds knowledge. The part of the name Smart aims to indicate that learning environments will be continuously evaluated and will use mobile technologies to teach.

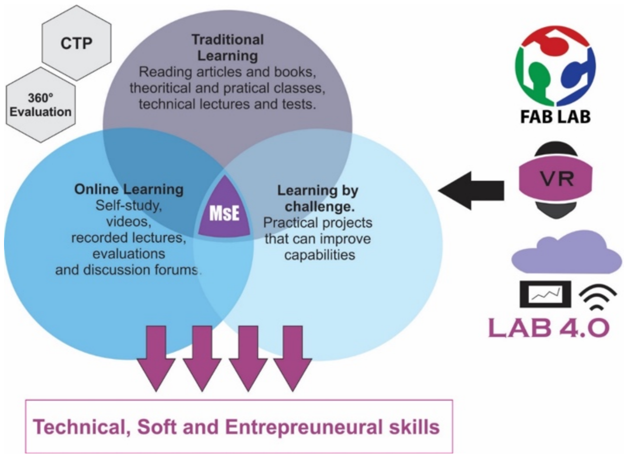

Fig. 1. Model MsE, adapted from Ferreira et al. (2019) [10]

One of the approaches that composes the model is the Traditional Learning, where the professor is the center of the learning process, using books, technical lectures, and tests to evaluate the student's knowledge. This traditional model is concerned with attaining knowledge of general and specific topics which will enable the future professional to perform the tasks. Face-to-face teaching refers to the traditional approach consisting of lectures and workshops and some group activities to develop students' soft skills. It can also include classical experiments to reinforce fundamental concepts discussed in a theoretical way. These experimental procedures are included within the traditional learning since they reproduce ideal conditions to reinforce the theory.

Online Learning was also considered to compose the integrated MsE model as it offers students the flexibility to reinforce the knowledge by self-learning through videos and recorded lectures and to be evaluated with online tests. The third is Learning by Challenge, where each semester, the professor poses a challenge to students and they address the project working as a team. The challenges force the students to deal with up-to-date realistic projects working in teams, collaborating, and innovating in more realistic situations. It also contributes to engaging students in writing a report and discussing to sharpen their skills. The ability to solve problems can be assessed instead of regular examinations.

According to Terkowsky, Fry and May (2019) [13] the student-centered learning environments and appropriate approaches gain more and more important in higher education because this is a critical way for the students to reach the high level of learning outcomes, and as a result of this development the basis of fundamental competences for their future professional and personal life, and attitudes like curiosity, agency, and responsibility.

The model MsE is supported by laboratories where the diverse technologies were adopted according to teaching specialists' opinions and made available for students training during the different undergraduate course stages. Selected technologies and devices were chosen through a committed decision that integrated specialists' responses, university profile, financial resources, and the methodologies adopted to present the technologies and enable students to handle them. The laboratories were developed with a vision to provide skills (technical / soft / entrepreneurial) for future engineers and the dimensions of the Brazilian curriculum guidelines, fig. 2, delimit the activities developed there:

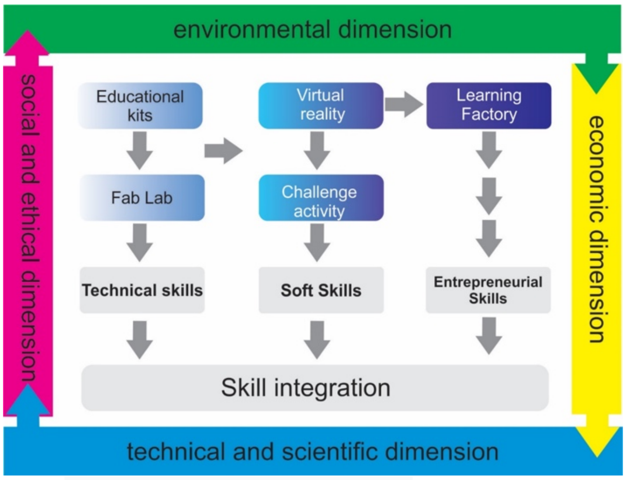

Fig. 2. Generic lab design for skill development

The laboratories can be tailored following the specific local needs and resources, provided that they contemplate the acquisition of the more relevant enabling capabilities to deal with the challenges of I4.0.

Since the model surges from evolution and integration, it is considered a dynamic entity that needs continuous control and improvement. The feedback is a way to maintain the improvement cycle and the coherence with industrial demands. In this way, fig. 1 also depicts a “360 evaluation” component, which can take diverse forms, such as questionnaires to collect the opinion of future engineers who were submitted to the teaching model, and new rounds of questionnaires for the industrial and teaching specialists. In the present paper, the proposal is a survey to validate or support the choices involving techniques and methodologies adopted.

2.1. MsE supporting technologies and methodologies

The contributions of each laboratory/technologies (Fablab, VR and I4.0 Lab shown in fig. 1) to the abilities the students should be able to fulfill will be described as follows. Also, the way the technology is presented and could be handled by the students is described. The 3D printing, one of the enabling technologies of Industry 4.0 [14], was one of the technologies selected through the teaching specialists [9]. It is an additive manufacturing process that produces objects layer by layer with a variety of materials. Among those that use thermoplastic or polymeric materials, there are three leading 3D printing technologies: stereolithography (SLA), fused filament fabrication (FFF), and selective laser sintering (SLS) [15]. The survey responded by academics of engineering courses revealed that the inclusion of 3D printing as a curricular knowledge helps catch student’s attention via the learning-by-making approach, more accessible concept teaching via visualization and promotes independent student learning [15]. According to Chong et al. (2018) [15] 3D printing/Industry 4.0 has helped improve students’ lifelong learning skills, such as being more proactive and independent and while invoking a more innovative and forward-thinking mindset. According to Stacey (2014) [16] Fab Labs can give entrepreneurs a low-cost space for designing and building prototypes, space where students engage in technology education and the community’s driven innovation to solve problems using local materials. In 2019, a Fab Lab was launched at Universidade Paulista, equipped with 3D printers (FFF and DLP processes) and hybrid equipment (laser cut and milling machine), where the Learning by Challenge approach can be implemented, and students can design, produce, test and improve their prototypes.

Virtual reality (as well as augmented reality) allows to create realistic, correctly scaled, three-dimensional images that speed up product design, optimize production and shorten time to market. The virtual reality (VR) can assist in student training by simulating industrial environments with industry 4.0 technologies. The application of these technologies is quickly increasing to support a wide range of disciplines, not only at academic and teaching levels, but also in real engineering and industrial processes [17]. According to Mourtzis et al. (2018) [18] VR can contribute significantly to manufacturing education. Some industries are currently using VR to simulate changes in processes, train their employees, save time, and costs, and provide immersive and realistic experiences in a safe environment.

The Industry 4.0 laboratory (Lab. 4.0) uses the fourth industrial revolution technologies to promote an environment where the students can change the process and see the results immediately. The selected technologies are well related to the disruptive technologies most cited in the literature between 2011 and 2019, according to Bongomin et al. (2020) [19]. Fig. 3 is a cloud representation where the size of words is related to the number of citations in a comparative way.

Fig. 3. The most cited disruptive technologies between 2011 and 2019 – adapted from Bongomin et al. (2020) [19]

Kits already developed (Robot arm with HMI and PLC with HMI) at UNIP and others in development process (RFID, MES, Cloud Computing, Cyber Security, sensors and maintenance) will help students develop the skills that the industry needs.

With simulations and VR, and a fast manufacture (3D printing) adoption, it will be possible to introduce to students how I4.0 impacts Society, work and the environment. To predict environmental impacts and to select more sustainable technologies are relevant for the new engineers since the contribution of I4.0 to sustainability could depend on the stage considered (deployment or operation) and on the degree of compliance with the sustainable development goals, according to Bonilla et al. (2018) [14].

3. Methodology

A questionnaire of a 5-point Likert-type scale was adopted to accomplish this research. Data were collected in May 2019 during the machine tools and industrial automation fair (EXPOMAFE), held in São Paulo city, Brazil. The university had a stand where it presented technologies and educational methods for engineers and technicians in the automation area. Data were analyzed using descriptive statistics and the Mann-Whitney-Test to compare two groups of industrial experts classified according to their self-evaluation on I4.0 expertise. This section was organized in sub-items to enable the reader with a better understanding of the whole procedure.

3.1 Questionnaires of Likert-type scale

One of the most popular ways to obtain self-report data from participants in evaluations, experiments, and surveys reported in the human-computer interaction literature are Likert-type scales [20]. Likert-type scales are used extensively to evaluate interactive experiences, including usability evaluations, to obtain quantified data regarding participants' attitudes, behaviors, and judgments [21]. Likert-type scales results in ordinal data. That is, the data ranked as "strongly agree" is usually better than "agree" [22]. For this research, a form with Five Likert-type response categories was developed where the industrial experts could choose among nothing useful, not so useful, relatively useful, very useful and extremely useful, as shown below:

The Likert scale is used to examine industrial experts' opinions of the usefulness of the techniques already selected by teaching experts to be implemented in engineering courses. The responses comprised from "nothing useful" to "extremely useful", the numbers from 1 to 5 were assigned to levels of usefulness, as follows;

- 1 = nothing useful
- 2 = not so useful
- 3 = relatively useful
- 4 = very useful
- 5 = extremely useful

The questionnaire was prepared by a panel of experts from the university using the Delphi methodology to establish an agreement about which questions should be asked, their scope and effectiveness. This process took in account the institutional reality [23]. The Delphi method is a versatile research tool that researchers can employ at various research points. Three statements are presented to the respondents on a Microsoft forms format to be answered according to their usefulness, as shown in Table 1.

Table 1. The three statements about technologies in Engineering education that were presented to the respondents to be answered according their usefulness.

Code	Statement
T1	In your opinion, what is the usefulness of creating an Industry 4.0 laboratory for training and research on the various technologies used in Industry 4.0 for Engineering students?
T2	In your opinion, what is the usefulness of using tools such as additive manufacturing or 3D printing, for training of Engineering students who will work in the context of Industry 4.0?
T3	In your opinion, what is the usefulness of using simulation software (such as Arena) and virtual reality, for training of Engineering students who will work in the context of Industry 4.0?

3.2 Data collection, sample size and groups division

For data collection, we sent a link by e-mail to all 58 professionals who were at the university stand in the fair, so that respondents could access and respond without interference. The forms were made using the Microsoft forms tool and the resulting database has no identification of who answered them. The sample was 51specialists (reliability 95% and margin of error 5%) who were willing to respond and were divided into two groups according to an initial self-qualification question shown in the Table 2. Thus, we decided to send the questionnaire to all professionals that visited our stand, and the sample of 51, although small it is suitable for the population of 58 professionals.

Table 2. The first question of the questionnaire: a self-qualifying question that allows classifying respondents into two groups according to their knowledge of I4.0 technologies.

Self-Qualifying question: **How advanced is your knowledge of Industry 4.0:**

Answer	**Classification (groups Division)**
Nothing advanced	Ordinary professional
Not so advanced	
Relatively advanced	Industry 4.0 professional
Very advanced	
Extremely advanced	

Those professionals who evaluated their knowledge of I4.0 as nothing or not so advanced amount 13, while the most advanced group in terms of I4.0 knowledge, amounts 35.

3.3 Data analyses and Statistic

It is common for researchers to use parametric statistics like the Student t-test or ANOVA to analyze Likert type responses. These methods are chosen to ensure higher statistical power of the test (which is necessary for this field of research and practice where sample sizes are often small), or the lack of software to handle multi-factorial designs nonparametrically [21]. Similarly, the commonly used Likert categories for responses to attitude statements, 'strongly agree', 'agree', 'neither agree nor disagree', disagree', and 'strongly disagree', are not necessarily evenly spaced along with this level of agreement continuum, although researchers frequently assume that they are. When this assumption is introduced, an ordinal-level measure becomes an interval level measure with discrete categories [24]. However, the Likert scale's appropriate analysis has led to endless debates and discrepant solutions [25, 26, 27]. The debate is mainly based on the ordinal (rank order) or the–intervals views in Likert scales [28]. Assuming an interval scale for Likert type categories is an important issue, because the appropriate descriptive and inferential statistics differ for ordinal and interval variables. Even so, Kapten, Nass and Makopoulos (2010) [21] through the examination of the CHI 2009 proceedings affirms that 80.6% of all the published articles using Likert-type scales use parametric tests (such as t-tests or ANOVA) and only 8.3% use a nonparametric technique for statistical inference.

Methodological and statistical texts are clear that for ordinal data one should employ the median or mode as the measure of central tendency because the arithmetical manipulations required to calculate the mean (and standard deviation) are inappropriate for ordinal data where the numbers generally represent verbal statements. Besides, ordinal data may be described using frequencies/percentages of response in each category. In this article, due to the data's ordinal nature, we used a nonparametric technique to analyze the results [29]. The Wilcoxon-Mann-Whitney Test (WMW) is a nonparametric alternative to the t-student (TST). Analysis of variance techniques could include Mann Whitney test or Kruskal Wallis test, in this case, Mann Whitney test because we have two groups, and the nullity hypotheses (H0) is that the sample medians are equal.

There are some softwares (free and paid) to run the Mann-Whitney test, such R (Free), SPSS (Paid) and EXSTAT - Excel Statistical Calculator (Free). We used the EXSTAT, a pack of open source VBA statistical tools for Microsoft Excel.

4. Results and Discussion

This section is organized as follows, firstly, a descriptive analysis of the results for the three statements, secondly, the frequency of the results split by score for the three statements and lastly, the inferential technique of Mann-Whitney to evidence differences if any between the two groups of professionals.

Table 3 shows the results relative to descriptive statistics for the three statements, by means the median, mode, range, first quartile (Q1), third quartile (Q3) and interquartile range (IQR) values.

Table 3 Descriptive Statistics

Descriptive Statistics						
	Median	**Mode**	**Range**	**Q1 (25%)**	**Q3 (75%)**	**IQR**
T1	5.0	5.0	3.0	4.0	5.0	1.0
T2	4.0	4.0	3.0	4.0	5.0	1.0
T3	4.0	5.0	3.0	4.0	5.0	1.0

The median was 5.0 for the first and 4.0 for the second and third statements, with an IQR of 1.0 (for all statements). The mode, representing the most frequent score chosen for the respondents' statements, is 5.0 for T1 and T3 and 4.0 for T2, suggesting a more remarkable agreement with the usefulness of Laboratory 4.0 and Virtual Reality than for additive manufacturing or 3D printing. Even considering the differences among descriptive results for the three statements, the level of acknowledgment of the respondents to the usefulness of all the techniques is high.

Table 4 shows the results organized by the score for the three statements (Likert level).

Table 4. Descriptive Statistics by statement and by score (Likert level) expressed in quantity of respondents and in percentage.

Descriptive Statistics - Likert level						
	q	**Nothing Useful (1)**	**Not so useful (2)**	**Relatively useful (3)**	**Very useful (4)**	**Estremely useful (5)**
T1	#	0	1	7	17	26
	%	0%	2%	14%	33%	51%
T2	#	0	1	8	24	18
	%	0%	2%	16%	47%	35%
T3	#	0	1	4	22	24
	%	0%	2%	8%	43%	47%

For the first statement, 84 % of respondents believe that Laboratory 4.0 is very or instrumental in using new engineers' training. The second statement shows that 82 % of respondents consider additive manufacturing or 3D printing very or extremely useful to use in the training of new engineers and for the third, 90% of respondents consider the same for Virtual Reality.

The non-parametric test of Mann-Whitney allows evidence of statistical differences between the two groups of professionals. The hypothesis to be tested is the null hypothesis H0, which affirms that there is no difference between the responses of both professionals' responses. Moreover, the alternative hypothesis affirms that there is a difference between the responses of both groups of professionals, regarding the usefulness of the techniques proposed for training engineering students. The p value is a measure of how much evidence there is against the null hypotheses. Table 5 provides the interpretation of p-values where the value above 0.10 indicates little or no evidence against H0.:

Table 5. Interpretation of p-values, adapted from [30], page 132.

p-Value	Interpretation
$p < 0.01$	Very Strong evidence against H0
$0.01 \leq p < 0.05$	Moderate evidence against H0
$0.05 \leq p < 0.10$	Suggestive evidence against H0
$0.10 \leq p$	Little or no real e evidence against H0

The hypotheses test for each statement (T1, T2 and T3) shows p-values between 0.18 and 0.38 (T1= 0.38, T2=0.18 and T3=0.38), so there is little or no real evidence for rejecting H0. Hence, the favorable results for the usefulness of the technologies do not differ between both groups (Ordinary and Industry 4.0 professional)

5. Conclusions

In previous research, a teaching methodology model was proposed, based on the opinion of educational experts. Those experts indicated that the model, which was called MsE, supported by a Fab Lab, simulations using virtual reality and a laboratory with some of the disruptive technologies of industry 4.0, would be vital for the education of engineers who will act in this context.

Industrial experts' opinion was collected to verify the previous research results' alignment with the real industry needs. As a result, we can observe that between 80 and 90% of the professionals interviewed agree that these technologies are very or extremely useful for the education of the professionals who will act in the context of I4.0. There was no significant dispersion in the results found, which shows an alignment in the opinion of the professionals interviewed. The results don´t show statistical differences between the two groups of professionals involved in it.

The results indicate an adequate level of agreement between educational and industrial experts' opinion, indicating that the technologies initially proposed were selected appropriately. It is hoped that the methodology can develop in engineering students the skills needed and expected by the labor market.

Nevertheless, the findings mentioned above cannot be generalized in Brazil industrial /educational specialists, as the research sample was not representative. Therefore, the repetition of the research in a representative sample of industrial specialists would be more suitable. Our research was focused on our university, we can involve other universities in Brazil and other countries in the future.

For future studies, we suggest research involving experts from other countries and specific research evaluating the Fab lab, the simulations in virtual reality, and the kits developed for LAB 4.0, to relate the skills and capabilities acquired using each technology. Although the feedback showed a good agreement between industrial needs and technologies proposed at the university level, continuous monitoring and feedback should be proposed.

The next step will be a specific training course with explicit material such as a guidebook or instructions for students, collaborating with the expertise from Industries. Then, evaluating the satisfaction level of students who took the course and analyzing the weaknesses and strong points of the teaching methodology.

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