Research Article

Analysis of Teachers' Competences for Industry 4.0 Subjects: A Case of Thai Higher Education Institutions

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Abstract
The era of Industry 4.0 (I4.0) requires technology and engineering higher education institutions to provide their students with the competences inherent to this evolution. This requires teaching staff training, but first, naturally, teachers' level of competences must be assessed. The objective of this work is to assess the current level of teaching staff self-perceived competences related to product, process, and production in the I4.0 Era, using a tailor-made questionnaire. Additionally, the work aims to evaluate the relation between academic degrees and years of experience, with the level of self-perceived competences. In terms of methodology, the development of the questionnaire's items was based on the Acatech framework and existing I4.0 courses. The questionnaire was validated through the following steps: 1) think-aloud procedures with 4 teaching staff, and 2) test and retest statistics validation, developed with approximately 30 teaching staff from the referred institutions. Then, the questionnaire was applied to more than 200 teaching staff. Two I4.0 areas showed a lower level of self-perceived competence: Data Analytics and Digital Manufacturing. It became evident that the teaching staff, regardless of their level of experience or academic degree, may benefit from organizational and people management training including processes and techniques related to I4.0.

Keywords: Industry 4.0, Teacher competences, Industrial engineering and management

1 Introduction

The Industry 4.0 (I4.0) term was used for the first time to designate the process of merging the digital/virtual world with the physical world; a major transformation underway after others, such as the mechanization of production (I1.0), mass production (I2.0), and the digitization of production and organizational processes (I3.0) [1]. I4.0 refers to the fourth industrial revolution, which introduces new requirements not only for industries around the world but also to the higher education institutions, which are responsible for the education of professional works in new environments, requiring new knowledge and competences to be included in the curricula [2]. These new requirements are challenging for all institutions in different engineering areas. In particular, in the Industrial Engineering area, many different fields may be explored, some more focused on technologies (e.g., Cyber-Physical Systems) and others more focused on methodologies (e.g., Data Analytics).

According to Kengpol *et al.* [3], for centuries, curricula have been exclusively designed and applied by professors for purposes related to educational interests. Nowadays, there is a common understanding that curricula must meet the needs of all stakeholders for the benefit of the society, which requires a refined articulation not only among higher education managers but also among all agents involved, including teachers and students. During the development of an international project, a consortium of six Thai and three European Union universities developed a master's degree program in Industrial Engineering for Thailand's sustainable smart industry [4]. After identifying 1) the gap between the programs currently in place [5] and 2) the needs of industry, students and teachers [6], the consortium prepared a modernized syllabus [7]. Based on the demands identified in a questionnaire among project stakeholders [8], important topics and themes were planned as a base for a development program of competences for industrial engineering, including digital economy, digital factory, simulation and optimization, data analytics, additive manufacturing, cyber-physical industrial systems, and other important topics in the context of I4.0, like project management, smart operations management, product design, quality management and supply chain management.

Developing students' competences to align with the new requirements of I4.0 and the referred new themes, require new curricula and adequate competences from teaching staff, as one cannot rely on curricular change without good support from teachers. As far as we know, the demand for teaching staff competences, to deal with I4.0 requirements in the context of higher education, has not yet been studied.

Thus, the objective of this work is to assess the level of self-perceived competences of the teaching staff working in industrial engineering areas to align them with the new requirements of I4.0. Considering this general objective, the specific objective of this work is to develop such a study in higher education institutions responsible for technological bachelor's degree programs in Thailand. This study will allow the development of recommendations for the training programs necessary to capacitate the teaching staff of those institutions. Additionally, this research work also aims to investigate the relation between the level of self-perceived competences in terms of both academic degrees and years of teaching experience. Thus, besides the main objective, this work also studied the following hypothesis:

H1: Teachers who have higher academic degrees have higher self-perceived competences.

H2: Teachers who have higher teaching experience have higher self-perceived competences. The main assumptions behind these hypotheses are that teaching staff with higher academic degrees and teaching staff with higher teaching experience will have higher self-perceived competences.

2 Materials and Methods

2.1 *Conceptual background*

Industry 4.0 brings new challenges in technology, management models and practices, and socio-cultural relations in a very diverse environment involving Large-Sized Enterprises (LE) and Small and Medium-Sized Enterprises (SME) [9]. In a particular way, the COVID-19 phenomenon reinforced the need for the digital transformation of processes and operations, and imposed a new environment for innovation, research and knowledge development [10].

This context also provides new challenges in education, namely in preparing professionals to deal with different situations and complex problems.

Naturally, this implies rethinking the development of competences by teachers, those who are inevitably the drivers of educational projects within this context, for being on the front line in the role of facilitating the teaching-learning process.

2.1.1 Industry 4.0

In the technological scope, I4.0 is enabled by Cyber-Physical Systems (CPS) that involve the Internet of Things (IoT), Internet of Services (IoS), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), additive manufacturing, collaborative and autonomous robotics, among other information and communication technology tools, sensing, and data analysis. However, the amalgamation of physical and digital systems has impacts that go far beyond infrastructure, that is, dimensions, such as organizational, cultural, and socio-technical systems also undergo significant changes [11].

Although it is commonly associated with electronic components and computers integrated into communication networks, the term Cyber-Physical Systems (CPS) refers to a panoply of resources that includes not only technology but also organizational processes and human relationships mediated by a digital universe of information. Therefore, technology, when in the scope of I4.0, needs to be observed as part of an integrated whole that has a certain level of autonomy responsible for ensuring its self-sustainability and stability [12].

The Internet of Things (IoT) has the function of establishing coordinated communication between technological components, in order to systematically collect data and make it available in a cloud structure. This data allows Data Analytics and AI algorithms to autonomously make decisions about problems or tasks that have a high level of structuring. It may additionally feed service layers in order to empower services (IoS – Internet of Services) to add value to customers. From the point of view of a company, services are permanent and physical products are the material support during their lifetime, being replaced and updated when needed, while the service maintains its continuity [13].

With the advent of additive manufacturing, even the physical product can become a service, as I4.0 provides economic engineering and business models where the design is ultimately the saleable product, linked to the 3D printing service [14].

Similar to AI algorithms that extend human capabilities in the realm of the mind by presenting themselves as support in decision making, collaborative robotics performs the same function, but in the motor aspect by providing smart and ergonomically adjusted support for performing manual activities [15].

Thus, in projects that imply digital transformations, it is fundamental of the incorporation of actions responsible for the evolution of the organizational architecture, as well as special attention to human resource management, for the dissemination of an appropriate organizational culture, compatible with a collaborative environment in which the traditional hierarchization of decision making must be overcome. The ultimate goal is for the organization to become agile and capable of continuous adaptation to a changing environment. The Acatech Industry 4.0 maturity index provides companies with guidance to achieve this transformation. It comprises a model, which allows to perform a diagnosis in order to identify the stage organizations in terms of the capabilities and competencies and enable them to be competitive in the I4.0 environment [16]. The model considers that the organizational architecture is based on four structural areas, namely, 1) tangible physical resources, including human resources, 2) information systems, 3) organizational structure, which corresponds to the design of business processes, and 4) culture, from which the behavior and attitudes of people are based [16]. This model comprises of the following six maturity stages: 1) computerization stage - the organization under analysis has a technological apparatus, however, without integration between; 2) connectivity stage - the technology is integrated and reflects the organizational processes; 3) visibility stage - the organization can monitor events and states regarding the processes; 4) transparency stage - the company can already count on a digital shadow from which knowledge can be produced; 5) predictive capacity stage - the company can simulate different future scenarios and identify the most probable ones, and; 6) adaptability stage - the organization has already reached a reasonable level of mobility and intelligence so that it can delegate the decisions of changes to the IT systems and can adapt continuously and with agility to the transformations of the environment [16].

2.1.2 Teacher competences

Lloyd and Payne [17] referred that in recent years, governments have found restructuring education as a way to promote economic prosperity and social inclusion.

The importance of education for the development of nations is a premise that is permanently on the agenda, it has been said many times and in different ways. However, there is one aspect that has gained relevance in recent years, which is the relationship of educational institutions with their external environment, and in particular, about the role of the teacher in this process. It is on this topic that [18] argues that professional skills and teaching competences are crucial factors that determine the success of educational projects, and, therefore, for Misra [19], continuous development of teachers' skills is essential.

Likewise, Dymock & Tyler [20] state that Continuing Professional Development (CPD) and Continuing Professional Education (CPE) can by no means exclude the teacher as a key element in the process of engaging education institutions with the development agenda, and Bound [21] identifies in teachers the essential link between these institutions and the world the social and economic relations.

Based on the study of examples in several European countries and UNESCO projects, Grollmann [18] advocates a model of education in which teachers can support learning processes not only technical or vocational (to prepare students for work with the general development of work-related attitudes and skills), but also about the role of citizens in society. Mourtzis *et al.* [10] add that due to the pandemic situation in recent years, technologies enabling distance education and online learning have developed substantially, and under the encouragement and organization of UNESCO, institutions have also prepared for this reality with special attention to low-cost and easy-to-use resources.

Misra [19] thus considers the continuous development of teaching competences to be an urgent requirement within the European Union. Grollmann [18] also argues that teachers should perform advisory functions for students, and also for other target groups such as employers, adult learners, and, additionally, that teachers should be able to manage the tasks concerning the organization and the curriculum with a perspective of continuous improvement of comprehensive education.

The research carried out by Lloyd & Payne [17], particularly in Europe, has identified that in the perception of representatives of economic agents, teachers have no familiarity with recent industry developments, and they are subjected to a tough chain of institutions responsible for their training that is full of gaps, and there are few coordinated efforts in the countries to integrate education into a national development project. In addition, Andersson & Köpsén [22] also call attention to the model that includes the figure of the "reflective practitioner", in which teachers are professionals who have a critical commitment to their practices and individually coexist in a circuit of permanent achievements that provide CPD experiences, such as coaching, mentoring, shadowing, peer support, peer observations, students' workplace learning (placements), involvement with professional bodies, educational trips, attending courses and workshops.

For Mourtzis, Angelopoulos & Panopoulos [23], however, the strategy for active education requires the involvement of all agents, namely, teachers, students, universities and civil society, so that the triangle of knowledge, Research, Education and Innovation, should be the basis for the operationalization of this approach. The authors [9] additionally suggest a hybrid model of education that involves face-to-face and distance moments to cope with the demands that have recently worsened with the pandemic and the need for digital transformation brought by Industry 4.0.

Thus, Mourtzis *et al.* [10] proposed a model composed of the concept of Teaching Factory, which connects the industry with the classroom in a bi-directional interaction of knowledge exchange, combined with the concept of Learning Factory. This model brings the university part of the resources and dynamics that happen in companies, with the participation of students, teachers and university, and connects with digital resources, virtual simulation environments, and cloud-based technologies.

This hybrid education model, which sets up physical and digital labs, as well as real experiences that take place in the real world, provides students with a meaningful experience. To do so, teachers need to reinforce their pedagogical competences, and the university to accomplish the effectiveness of its overall mission.

2.2 *Methods*

This section describes the methodology for the construction of the questionnaire for self-assessment of competences related to I4.0, and the procedure for collecting information and assessing the data. The design of the capacity assessment tool comprised the following phases: 1) development and identification of critical knowledge; 2) development of items (questions) for each dimension; 3) improvement of the questionnaire using the think-aloud technique; 4) measurement of the reliability of the questionnaire using test and retest validation followed by an improvement of the items; 5) application of the questionnaire; 6) data analysis and reporting. The target group was defined considering the domain and purpose of the assessment, as being the teaching staff working in industrial engineering areas and similar, of higher education institutions in Thailand.

2.2.1 Development of items

The items should be relevant to the domain and purpose of the assessment and must be related and relevant to the dimension to be assessed. In other words, it is a matter of assessing the relevance, saturation, dimensionality, or correspondence between the item and the characteristic to be assessed. With regard to the criterion of credibility, face validity, or 'apparent validity', the item should not appear ridiculous, or unreasonable. As for the clarity of the item, as a rule, short sentences or simple expressions should be used [24]. Items are constructed to objectively assess a given latent reality i.e., dimensions or variables that may also be referred to as constructs [24]. A construct is related to a concept that should be observable.

Considering the domain and purpose of the assessment, it was necessary to acquire critical knowledge through bibliographic research on I4.0, aiming to develop a questionnaire to be applied to the teaching staff, working in industrial engineering areas and similar, of higher education institutions in Thailand. Note that from this point on the term "teacher" will be used to refer to "teaching staff" in order to simplify the text and data presentation.

To integrate I4.0 content in the questionnaire, the Acatech maturity model and the courses developed in a previous ERASMUS+ project were used as theoretical foundations for item development. The full list of the questionnaire items can be found in the appendix, and is divided according to the following main content-related dimensions:

A) Industry 4.0 Generic Items based on Acatech Elements

B) Module 1.1: Industrial management in the industry 4.0 era

C) Module 1.2: Applications of optimization, and technology in the value chain

D) Module 1.3: Digital manufacturing

E) Module 1.4: Innovative product design and development

F) Module 1.5: Data analytics

A Likert-type scale was defined to reinforce the objectivity of the items. As this questionnaire was aiming to self-assess the competences, the chosen Likert scale was a 5-point agreement scale: 1-strongly disagree, 2-somewhat disagree, 3-not sure, 4-somewhat agree, and 5-strongly agree.

Besides developing the items related to I4.0, the questionnaire also included an initial part to characterize the participants and a final part to collect open comments.

During the development phase (five weeks), a team of four members carefully developed the items considering a simple way to write them. As much as possible, the items show a correspondence of "one item - one task, one task - one idea". A weekly 2-hour meeting was implemented for alignment and revision. After this initial process, the items were reviewed by a group of ten additional researchers from the industrial engineering area of knowledge. Finally, it was possible to start the validation phase.

2.2.2 Think-aloud – procedure

The think-aloud research procedure also referred to as "cognitive interviewing" and "verbal protocols", aims to understand how respondents perceive and interpret questions, and to identify potential problems that may arise in questionnaires. It should be carried out during the pre-test phase, before application. Aspects, such as attention span, word recognition, action, memory, language processing, problem-solving and reasoning may be assessed, exploring how knowledge is organized in memory and how memory is retrieved in relation to completing questionnaires. The procedure is carried out in a controlled environment with participants who match the characteristics of the proposed sample and involves an interviewer asking the respondent to think aloud while going through the questionnaire and telling him everything what he/she is thinking, while the interviewer asking probing questions to discover the respondent's thoughts [25].

The think-aloud procedure was implemented, in four virtual sessions, each one with a teacher who read and thought aloud about their interpretation of each item. Each session had one interviewer and two observers. One of the observers was a Thai researcher who intervened at the beginning whenever needed to clarify the process as a whole.

The interviews were of the concurrent type, i.e., the respondents gave verbal accounts of their thoughts as they answered the questionnaire. During the think-aloud procedure, the following occurrences were identified: comprehension difficulties, ambiguities in the interpretation and identification of typing errors.

After this step, the text was revised taking into account the reported problems. Based on the discussions, one item was eliminated, some items were simplified, less usual words were changed for more accessible terms and the sentences were improved. In summary, from the 98 items, one was eliminated, and 34 were changed (34.7%).

2.2.3 Test and retest – procedure

Measuring the reliability of the questionnaire was performed using a test and retest technique. The test corresponded to the application of the survey to a set of respondents and then, after a week, the same questionnaire was applied again (retest). This procedure measures the stability of scores across time and can be affected by the length of time between the applications of the survey. Moreover, the sample of respondents should be as homogeneous as possible.

If the scores from test and retest are highly correlated with stable scores and error variability across time, then reliability can be assumed. Correlations and t-student tests will be used to infer about reliability. Statistically significant correlations with correlation coefficients above 0.7 indicate reliability, otherwise, there is no evidence of reliability [26]. The t-student tests allowed conclusion about the existence of similar average scores between test and retest.

2.2.4 Test and retest - consistency analysis

To measure the reliability of the questionnaire, the test and retest technique was applied. The goal is to identify discrepancies in the answers, which would point to possible problems in the items. This procedure was carried out by 43 people who have the same profile as the questionnaire's target audience. Of these 43, just 31 participants answered the questionnaire and, after a one-week interval, repeated the same procedure. The answers were analyzed by the software SPSS – Statistical Package for the Social Sciences [27].

Intraclass Correlation Coefficient (ICC) was computed to infer reliability. According to [28], ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability and values greater than 0.90 indicate excellent reliability. ICC was computed for the original 5-classes Likert-type scale (ICC5) and a 3-class Likert-type scale (ICC3). The 5 classes Likert-type scale comprises the following classes: 1-"Strongly disagree", 2-"Somewhat disagree", 3-"Not sure", 4-"Somewhat agree" and 5-"Strongly agree". For the computation of ICC3, the previous classes were recoded as 1-"Strongly or somewhat disagree", 2-"Not sure" and 3-"Somewhat or strongly agree". Good or moderate reliability in terms of ICC5 was observed in items A1, B2, B3, B5, B9, C8, D7, and E1. Regarding ICC3 values, good or moderate reliability was just identified for items B5, D7, and E1. Based on the computed correlation values, 68 out of 97 (70%) of the items of the questionnaire have poor reliability. Paired t-student tests were performed to test the existence of significant differences between the average scores in the test and retest. For all items, there are no significant differences between the average scores in the test and retest, except for the G1 item.

2.2.5 Test and retest – improvement of the questionnaire

The 68 unreliable items mentioned in the previous section were analyzed and, whenever possible, revised, to make them less susceptible to ambiguities in interpretation. During this process, 51 out of 68 unreliable items (75%) were revised.

The items of module A - Industry 4.0 Generic Items based on Acatech Elements, required the revision

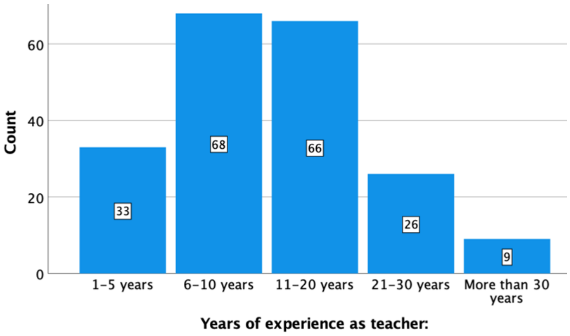


Figure 1: Distribution of the number of years of experience as a teacher. The bars indicate the number of teachers for each category.

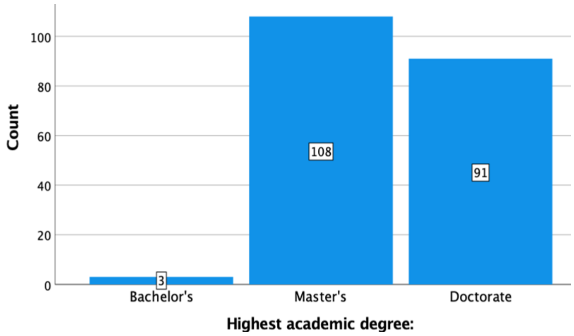


Figure 2: Distribution of teachers' highest academic degree. The bars indicate the number of teachers for each academic degree.

of 13 of its 14 items. Module E - Innovative Product design and development, required the revision of a single item, being thus the module with the lower number of changes.

2.2.6 Sample characterization

This section presents a characterization of the sample related to the survey results. The capacity assessment was conducted through a questionnaire sent to Higher Education Institutions around the Northern, North-eastern, Central, and Southern Parts of Thailand. The application of the questionnaire was conducted for one month, in June 2021. The responses were confidential, accessed only by a small team of researchers, but the login was required to guarantee a one-to-one relation between answers and respondents.

There were 211 answers, and 9 of them were considered to be not valid because the respondents were from institutions not included in the target group. Thus, 202 valid answers were obtained, comprising 131 male (65%) and 71 female (35%).

The distribution of the number of years of experience a teacher presents is depicted in Figure 1. Considering the way this information was collected in the questionnaire, the categories with a higher number of answers are the categories 6 to 10 years of experience, and 11 to 20 years of experience.

Figure 2 shows the distribution of the highest academic degree. The majority of the respondents from this type of institution has master's degrees and doctorate degrees.

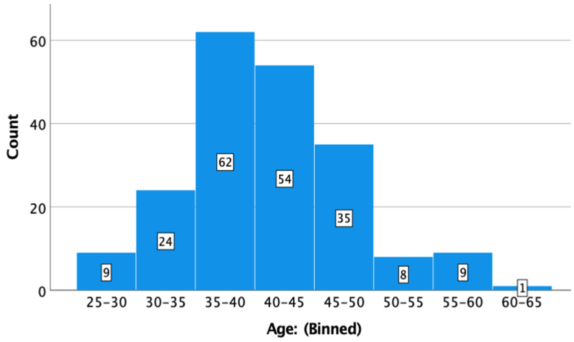


Figure 3: Distribution of teachers' age. The bars indicate the number of teachers for each age class.

The age distribution is presented in Figure 3. The mean age for teachers is 41.6 years with a standard deviation of 6.9 years.

3 Results and Discussion

This section presents the survey results, encompassing a consistency analysis using the Cronbach's alpha reliability coefficient (section 3.1), descriptive statistics (section 3.2) and the correlation between respondent characteristics and items (section 3.3). In section 3.4, the results are discussed, and recommendations are given in section 3.5.

3.1 *Consistency*

Cronbach's alpha assesses the consistency or reliability of sets of items, which is considered good with values superior to 0.8 [29]. All Cronbach's alpha values are

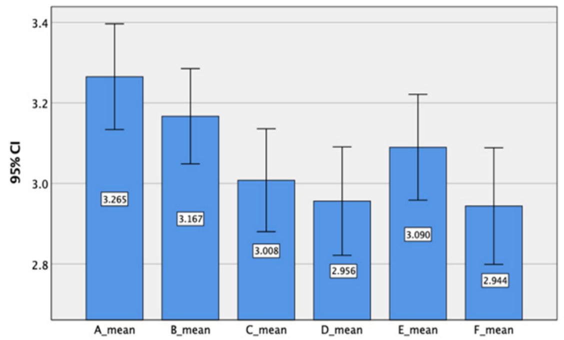


Figure 4: Questionnaire modules mean and 95% confidence interval. Bars indicate the mean value for each module.

superior to 0.9 corresponding thus to excellent levels of internal consistency: A - 0.976; B - 0.974; C - 0.956; D - 0.978; E - 0.958; F - 0.983.

The modules' means and the 95% Interval Confidence (IC) for the means of each module are given in Figure 4. The mean scores of the items, in each module, range from 2.956 to 3.587 and the standard deviations are quite similar. Module F (Module 1.5: Data Analytics) and module D (Module 1.3: Digital Manufacturing) are the ones with lower scores.

3.2 *Descriptive statistics*

This section presents the descriptive statistics for the results regarding each module of the questionnaire.

3.2.1 Generic items based on acatech elements

The mean scores of the items of module A - Industry 4.0 Generic Items based on Acatech Elements, range from 3.18 (items A2, A6, A7 of the appendix) to 3.56 (item A1 of the appendix) and the standard deviations are quite similar. The mean value for the entire module is 3.265 (Figure 4) thus corresponding to a self-perceived competence level of 65.3%.

3.2.2 Module B: Industrial management in industry 4.0 era

The mean scores of the items of module B range from 2.99 (item B7) to 3.31 (item B5). The mean value for the entire module is 3.167, thus corresponding to a self-perceived competence level of 63.3%.

3.2.3 Module C: Applications of optimization, and technology in value chain

The mean scores of the items of module C range from 2.94 (item C4) to 3.10 (item C6). The mean value for the entire module is 3.008 thus corresponding to a self-perceived competence level of 60.2%.

3.2.4 Module D: Digital manufacturing

The mean scores of the items of module D range from 2.80 (item D6 and D8) to 3.14 (item D1). The mean value for the entire module is 2.956, thus corresponding to a self-perceived competence level of 59.1%.

3.2.5 Module E: Innovative product design and development

The mean scores of the items of module E range from 2.94 (item E6) to 3.29 (item E1). The mean value for the entire module is 3.090, thus corresponding to a self-perceived competence level of 61.8%.

3.2.6 Module F: Data analytics

The mean scores of the items of module F range from 2.86 (item F8) to 3.07 (item F5). The mean value for the entire module is 2.944, thus corresponding to a self-perceived competence level of 58.9%.

3.3 *Analysis of the effect of respondent characteristics on items scores*

Associations between the number of years of experience and the highest academic degree, and the mean scores for modules A, B, C, D, E, and F were tested. Figure 5 shows the distribution of the number of years of experience as a teacher in terms of the highest academic degree. The association between these two variables was tested using the Chi-square test of independence. The null hypothesis H_0 is that the number of years of experience as a teacher and the highest academic degree are independent. No significant association was found between the variables (Q = 14.4 with a p-value = 0.07 > 0.05).

Analysis of Variance (ANOVA) is a parametric test that allows to compare means of different groups. The outcome is the F statistic that is the ratio between

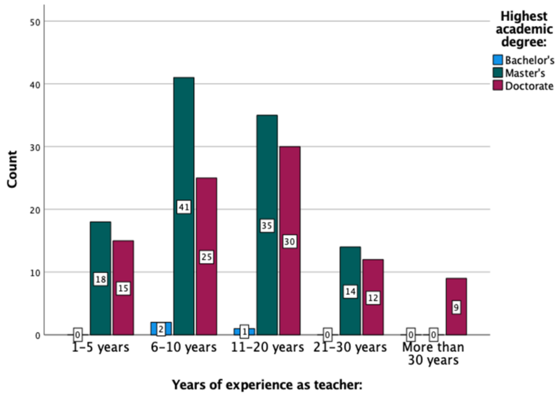


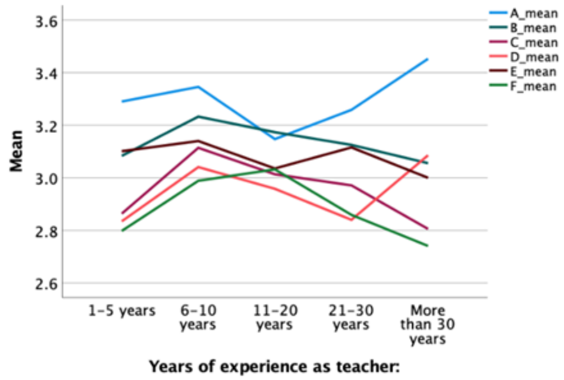
Figure 5: Distribution of the number of years of experience in terms of the highest academic degree. The bars indicate the number of teachers for each academic degree and number of years of experience.

the within group variance and the between group variance. Table 1 presents the F statistic value and the corresponding *p*-value obtained using an ANOVA to test if the mean scores for modules A, B, C, D, E, and F differ with the number of years of experience and the highest academic degree.

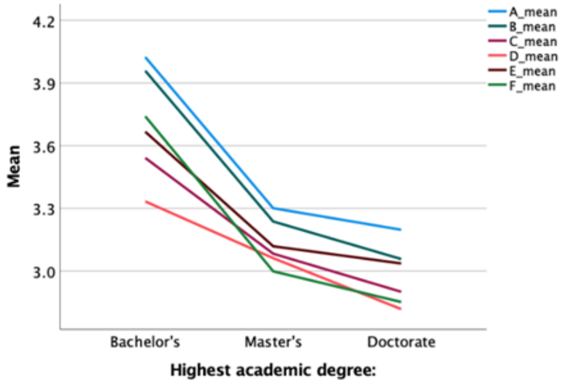
Table 1: ANOVA results for the number of years of experience and the highest academic degree. The F test statistic value and the corresponding *p*-value are given

	Number of Years of Experience		Highest Academic Degree	
	F	*p*-value	F	*p*-value
A	0.469	0.759	1.276	0.281
B	0.232	0.920	2.446	0.089
C	0.543	0.704	1.486	0.229
D	0.386	0.818	1.800	0.168
E	0.126	0.973	0.749	0.474
F	0.433	0.785	1.380	0.254

The assumptions (normality and homogeneity of variances) for the application of ANOVA were also tested. The results indicate that these assumptions are satisfied. Therefore, the ANOVA analysis was carried out. Two null hypotheses were tested: H1: There are no significant differences between the mean scores for modules A, B, C, D, E, and F due to the number of year of experience as a teacher and H2: There are no significant differences between the mean scores for modules A, B, C, D, E, and F due to the highest academic degree obtained by teachers. No significant differences were found between the number of years of experience and the mean scores of all modules (*p*-values > 0.05). The same occurred in terms of the highest academic degree.



(a)



(b)

Figure 6: Modules' mean scores by the number of years of experience as a teacher (a) and the highest academic degree (b). Lines represent the behavior of modules mean scores as the years of experience as a teacher and the highest academic degree vary.

Figure 6 shows the modules' mean scores by (a) the number of years of experience as a teacher and (b) the highest academic degree. These profile plots show the relative behavior of the modules' mean scores of the years of experience as a teacher and the highest academic degree vary. It can be observed that the modules' mean scores are consistently higher for 6–10 years of experience and then tend to decrease except for modules A and D. It can also be seen that the module's mean scores are inferior for higher academic degrees.

3.4 *Discussion*

The analysis of the results shows that the lowest mean self-perceived competence level (59%) occurred for module F - Data Analytic, while the mean highest score (63%) was attained by module A.

more detailed analysis of each dimension follows, which is based on the details of each item in every dimension. The analysis will highlight mainly the items where more than 55% of the participants chose disagreement or "not sure" options. The rationale behind this analysis is that in this case most of the participants show a lower self-perceived competence level and for that reason, they may benefit from training opportunities in those competences.

Regarding the general notions about I4.0 according to the Acatech elements, the results show the following trends concerning the respondents' competences: there is a prevalence of familiarity with basic concepts on the resources needed for I4.0 (technology) and maturity models as a tool for reconfiguring processes and business models. The validity of this hypothesis can be seen in item A1, where 36% are unsure about the question or disagree that they can assess it, and 64% consider themselves comfortable with it. The answers are somehow similar for items A3, which deals with the physical resources employed in I4.0, A4, which is related to the technological aspect of the Information Systems, and A8, related to efficient communication between people and between people and machines. However, most of the respondents do not consider themselves secure about the development and execution of I4.0 implementation projects, as stands out from item A2, about the application of technology for coordinated data collection (A7), the internal organization required (A5), managerial aspects of information systems (A10), and general aspects of organizational culture and other specific ones that involve concepts such as collective intelligence, collaborative management and appreciation of innovation and change (A6, A9, A11, A13, A14).

The answers indicate that more than half of the respondents do not agree or are not sure about topics of I4.0. The only questions where this did not happen markedly (less than 60% of the answers) were those about general topics such as being able to discuss agile project management concepts in the context of I4.0 (B1), the ability to work in distributed teams (B5), knowledge about production planning and control (B10), plan and control the company's operations considering smart production concepts (B11), quality management (B12-15), general concepts about digital factory and digital technologies (D1, D2), and general concepts about innovation (E1, E3, and E4). However, in a large number of cases with the expression "in the context of Industry 4.0", the answers indicate an apparent tendency for disagreement.

As could be seen in different studies there is a need to develop a systemic overview of the whole, encompassing the various dimensions of I4.0, going beyond the technological view [11], [16]. The results show that the teaching staff does not yet have this global understanding. Moreover, in all questions, there is a high rate of answers that indicate the need for the development of the themes.

In the analysis of the answers referring to Module B, the lower self-perceived competence levels are those about the application of maturity model assessment (B2), application of agile project management techniques (B3), team development (B4), development projects of business process reconfiguration (B6), business process modeling (B7), use of performance indicators (B8), and about the role of customer-oriented services (B9). Considering that the willingness to cooperate is seen as one of the main barriers to the implementation of I4.0 [30], and also that market conditions, continuous monitoring and improving efficiency are driving forces [30], some of these lower self-perceived competences are of the utmost importance and should be included in training opportunities.

In module C - Applications of optimization, and technology in the value chain, which is basically a module on the application of concepts and techniques, all items have 60% or more responses that indicate demands for the development of teaching competences, especially in the ability to conduct sensitive analysis (C4) in which 71% of the participants responded that they have no knowledge on the subject or were not sure. The other items also presented high indexes in this same path, which may indicate the need for training in the development and application of optimization models (C1-3, C5), and application of optimization models in Supply Chain Management (SCM) (C6-8).

All supply chain functions will be affected by I4.0, particularly order fulfillment and transport logistics [31], but special attention should be paid to the supply chain resilience, as few works have been published so far [32]. Although the study participants show a lack of competences in optimization models, it is clear from recent developments that these are required competences to explore the full potential of I4.0 [33]–[35].

In Module D - Digital manufacturing, in several items, more than 70% of the participants answered that they were not skilled in concepts, such as cyber-physical system (CPS) and its applications (D5, D6 and D8), and, similarly, in additive manufacturing (D11, D13). When asked about general notions about these technologies, this rate improves somewhat but remains above 60% for those who consider they do not have enough knowledge about these subjects (D9, D10 and D12). With similar indexes, the answers indicate that the respondents present demands in the use of simulation models for performance analysis (D3), and related techniques and applications, such as digital technologies and their limitations for the development of digital factories, specification of digital transformation models (D4) and use of Internet of Things (D7).

Digital manufacturing encompasses the main technological themes more commonly identified with I4.0 [11], namely cyber-physical systems [12], internet of things [13], additive manufacturing [14], artificial intelligence [15], augmented reality (AR) and virtual reality (VR) [36], where most of the participants showed lack of self-perceived competences. This result indicates that most of the industrial engineering teaching staff may not be considered specialists in the referred areas, but also that there is the need to carefully know how to integrate these technologies in management systems.

Regarding module E - Innovative product design and development, 70% of the answers indicate needs in the subject of valorization (E6), capitalization and protection of products and intellectual property in innovation policies. Regarding the techniques applied in the innovation process, the respondents also indicate accentuated demands, namely the analysis of strategic elements of innovation (E2), techniques of development of ideas for innovation (E3), application of innovation methods (E4) and development of marketing strategies in the innovation process (E5).

Market trends and business model innovation are seen as driving forces [30] of I4.0, which create the need to develop competences that have been identified as lacking and that must be articulated with the following I4.0 dimensions: marketing strategies with higher integration of customers in design processes [37], [38], servitization [39] and smart and connected products [40].

In module F - Data analytics, more than 72% of the participants responded that they were not skilled in the development of data analytics algorithms (F8) and in the design and development of projects in this area (F4 and F9). There is also still a strong perception (more than 60%) of the need to develop skills in general knowledge of the Intelligent Decision Support System (IDSS) (F1 and F3) and the application of its techniques (F2). The same occurs regarding the principles of data analytics (F5) and the application of techniques related to this area (F6 and F7).

Data analytics is one of the most recognizable dimensions of I4.0 [41], with an increased importance factor due to big data coming from sensors, smart products [40] and smart business systems [42].

3.5 *Recommendations*

The competences' assessment of teachers was conducted through a self-perception questionnaire that covered knowledge of I4.0. Based on the evaluation of the questionnaire responses, it is possible to present the following recommendations.

The answers indicate that the participants have general knowledge about I4.0 - definition, needs and impacts, and can point to the technology that makes I4.0 possible, such as Artificial Intelligence, Machine Learning and the Internet of Things. However, the answers related to the self-perceived competence level show that the target audience has a higher opportunity for the development of competences mainly in the following domains: organizational, people management, methodologies, and techniques:

Organizational: development of a business strategy for adequacy to the I4.0 environment (external factors) that favors the provision of services for adding value to products and correlated digital reconfiguration of business processes (internal factors). This requires the development of competences in the design and application of maturity models, agile project management applied to business process reconfiguration, use of business process modeling tools, development and application of performance indicators, design of data collection strategies and use of data analysis for decision making, and operations management in the context of I4.0.

People management: strategy design and application of techniques and resources for project management in the context of I4.0 with emphasis on agile philosophy and team development.

Methodologies and techniques: technologies associated with digital factory or Cyber-Physical System (CPS), use of Internet of Things (IoT), development of strategies and implementation of Additive Manufacturing, product development and innovation in the context of I4.0, implementation of Intelligent Decision Support System (IDSS) with data analysis, development and application of data analysis algorithms and development and application of simulation models and simulation techniques.

4 Conclusions

A questionnaire was used to analyze the level of self-perceived competences of the teaching staff working in industrial engineering areas and related fields, to align with the new requirements of I4.0, in higher education institutions responsible for technological bachelor's degree programs in Thailand. Additionally, it was possible to study two hypotheses that were both refuted. Considering that the demands of I4.0 are very recent, neither the previous experience nor the level of academic development proves to differentiate the self-perceived level of competence. Thus, the study allowed us to conclude that all teaching staff require training for this new context. Beyond the recognition of this need based on evidence, the study contributed also with an instrument for the identification of self-perceived competences by teaching staff in higher education institutions.

Future work may present similar studies related to pedagogical competences and identify the need for development regarding different teaching and learning approaches. Furthermore, it would be relevant for the development of engineers and technological areas, and so for the development of engineering and technology, that training may be defined for attaining the requirements of I4.0.

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Author Contributions

R.M.L., R.M.S., L.C., C.J.: conceptualization, questionnaire validation, investigation, data curation, data analysis, writing an original draft, reviewing, and editing; D.M.: conceptualization, questionnaire validation, investigation, reviewing; A.K.: questionnaire validation, data collection, reviewing; W.M.: data collection, reviewing; P.K.: conceptualization, reviewing, funding acquisition. All authors have read and agreed to publish this version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix – Questionnaire items

A. Industry 4.0 Generic Items based on Acatech Elements

A1. I am able to understand that companies have different Industry 4.0 maturity levels.
A2. I am able to evaluate the maturity level of a company in order to develop a project to evolve its Industry 4.0 stage.
A3. I am able to recognize a company required tangible, physical resources, including a company's workforce (human resources), facilities, machinery and equipment, tools, materials and the final product for Industry 4.0.
A4. I am able to discuss the required information systems for Industry 4.0, in which the information is provided by both people and "information and communication technology".
A5. I am able to recognize the required Industry 4.0 organisational structure, referring to both a company's internal organisation (structure and operational processes) and its position within the value network (value stream).
A6. I am able to discuss the required learning and agile corporate culture, including being willing to change, innovate, and develop employees' skills, in the context of Industry 4.0.
A7. I am able to understand the importance of digital capability for decentralized pre-processing of automated data acquisition through sensors and actuators.
A8. I am able to understand that Industry 4.0 includes efficient communication between people and between people and machines through task-based interfaces.
A9. I am able to understand the importance of data and self-learning systems for delivering context-dependent data.
A10. I am able to understand that Industry 4.0 information systems must provide a full integration between processes under governance policies and be protected by data security systems.
A11. I am able to understand that in the context of Industry 4.0 the organization is a system enabled by collective intelligence and agile management, i.e. involving motivation to change (problem-solving, improvement), proper use of people skills and decentralized decision-making.
A12. I am able to understand that Industry 4.0 is focused on the customer benefits enabled by networked collaboration inside the company (i.e. intra-company) and between different companies (i.e. inter-companies).
A13. I am able to recognize that collaborative management is important in the context of Industry 4.0, i.e. including democratic leadership and transparent communication between people.
A14. I am able to discuss that in the context of Industry 4.0, people recognize the value of mistakes, are open to innovation, search for continuous professional development and are driven by knowledge databases and decision-making in a continuous process of change.

B. Module 1.1: Industrial Management in Industry 4.0 Era

B1. I am able to discuss the relevance of agile project management in the context of Industry 4.0.
B2. I am able to define the Industry 4.0 level of maturity of a company.
B3. I am able to apply agile project management approaches in the context of Industry 4.0.
B4. I am able to apply the team development phases (Forming, Storming, Norming, Performing, Adjourning) to support teamwork.
B5. I am able to work effectively in a distributed team.
B6. I am able to develop projects for the transformation of a company in the context of Industry 4.0.
B7. I am able to use a modelling tool (e.g. BPMN, VSM) to represent industrial processes considering smart production concepts.
B8. I am able to use performance indicators of a company's operating efficiency in the context of Industry 4.0.
B9. I am able to recognize the role of customer service in the context of Industry 4.0.
B10. I am able to plan and control the company's operations considering smart production concepts.
B11. I am able to design real-time data analytics systems to support operations planning and control.
B12. I am able to discuss the impact of Industry 4.0 on quality management.
B13. I am able to identify performance indicators in the quality management area in the context of Industry 4.0.
B14. I am able to collect quality management data for Industry 4.0.
B15. I am able to design a data visualization solution for quality management and productivity indicators.
B16. I am able to design a quality management system for Industry 4.0.

C. Module 1.2: Applications of Optimization, and Technology in Value Chain

C1. I am able to formulate mathematical optimization models for practical problems in industrial applications.
C2. I am able to select appropriate optimization techniques to solve practical problems in industrial applications.
C3. I am able to use optimization software (e.g. MATLAB, LINGO, or MPL software) to solve practical problems in industrial applications.
C4. I am able to conduct sensitivity analysis to examine solutions robustness.
C5. I am able to develop real-time optimization approaches for Industry 4.0.
C6. I am able to describe Sustainable Supply Chain Management (SSCM) models.
C7. I am able to manage a Sustainable Supply Chain Management (SSCM) network in the context of Industry 4.0.
C8. I am able to redesign a supply chain considering sustainability and Industry 4.0 requirements.

D. Module 1.3: Digital Manufacturing

D1. I am able to describe the concept of Digital Factory.
D2. I am able to understand the functionalities and limitations of current digital technologies.
D3. I am able to use simulation to analyse the performance of a production system.
D4. I am able to specify a digital transformation model for an industrial case study.
D5. I am able to describe the concept of Cyber-Physical Systems (CPS).
D6. I am able to implement concepts of Smart Production using Cyber-Physical Systems (CPS).
D7. I am able to use the Internet of Things (IoT) to collect real-time data from sensors.
D8. I am able to develop Cyber-Physical systems (CPS) projects to improve business performance.
D9. I am able to describe principles of Additive Manufacturing.
D10. I am able to apply Reverse Engineering concepts in the context of Additive Manufacturing.
D11. I am able to choose process parameters for effective Additive Manufacturing.
D12. I am able to choose Additive Manufacturing technologies.
D13. I am able to develop products using the Design for Additive Manufacturing (DfAM) concept.

E. Module 1.4: Innovative Product Design and Development

E1. I am able to recognize the benefits of implementing innovations.
E2. I am able to analyse strategic elements of new product innovation.

E3. I am able to identify ideas for innovative products in the context of Industry 4.0.
E4. I am able to apply methods for innovation (e.g. design thinking).
E5. I am able to propose marketing strategies for launching new products.
E6. I am able to valorise, capitalize and protect (e.g. using patents) the original solutions obtained from the creative activity.

F. Module 1.5: Data Analytics

F1. I am able to describe the concept of an Intelligent Decision Support System (IDSS).
F2. I am able to apply techniques of Intelligent Decision Support Systems (e.g. artificial neural networks, machine learning or rule-based systems) to solve industrial problems.
F3. I am able to describe a framework for Intelligent Decision Support System (IDSS).
F4. I am able to design an Intelligent Decision Support System (IDSS) to support a smart production system.
F5. I am able to identify data analytics principles.
F6. I am able to apply data visualization techniques in dealing with big data sets.
F7. I am able to apply key data mining techniques (e.g. classification analysis, clustering analysis, regression analysis) in dealing with big data sets.
F8. I am able to develop data analytics algorithms for big data sets.
F9. I am able to develop data analytics projects in the context of Industry 4.0.