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Food engineering: Attitudes and future outlook

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ABSTRACT

A global web survey was conducted collecting academia and industry perceived attitudes, identifying curriculum gaps, challenges and opportunities of food engineering (FE). Participation criterion was: "A person who has one or more formal degrees in FE, and/or an equivalent degree in another field and whose job description includes/included FE activities". Respondents with formal FE education was lower than 25%. More than two-thirds of the respondents holding a formal BSc or MSc in FE selected other domains for their higher degrees, and 56.7% indicated that FE should become a part of another study program. Traditional FE topics were preferred over health, nutrition and wellbeing, innovation related to firm's activities, marketing molecular biology. FE profession should undergo a self-examination required to ensure its future growth and impact in addressing forthcoming challenges in the food sector, and concurrently make paradigm shifts in its vision in the pursuit of excellence and innovation.

1. Introduction

Surveys are widely utilized to assess and identify gaps in various domains. For instance, the American Society for Engineering Education (ASEE) interviewed in what is known as Phase I over 100 volunteers. The objective was to catalyze a conversation within the U.S. engineering community on creating and sustaining a vibrant engineering academic culture for scholarly and systematic educational innovation, ensure that the U.S. engineering profession has the right people with the right talent for a global society (ASEE, 2009). In Phase II a survey of faculty committees, chairs, and deans was conducted. Narrative and quantitative responses from 110 departments representing 72 colleges provided insights into current views and practice in teaching and learning, faculty preparation and engagement, and infrastructure and support for engineering education innovation (ASEE, 2012).

Phase II highlighted that as engineering careers have become increasingly collaborative, multidisciplinary, entrepreneurial, and global, and as the pace of change of technology has accelerated, the expectations for engineering education have expanded and include interdisciplinary breadth, communication, teamwork, global economic, environmental, and societal contexts, critical thinking, ingenuity, creativity, leadership and flexibility (ASEE, 2012). A more recent study utilized the ASEE survey data to identify promising pathways for transforming engineering undergraduate education. It concluded that the greatest promise for transformative change in engineering education lies in developing a shared vision for educational innovation (Besterfield-Sacre et al., 2014).

The food engineering (FE) profession is at a crossroads. Continually diminishing support from the government and other agencies, together with a lack of critical mass among university faculty particularly in the United States has taken a heavy toll on research activity, attractiveness to young students, and new academic positions. Noteworthy proliferation and flourishing of many biology disciplines has highlighted an immediate acute need for the FE profession to reassess its vision, strategy and mission to reinvigorate the domain and to sustain its future (Saguy et al., 2013).

The cliché that 'you can't compete today with yesterday's technology' is well known; food engineers should adopt new paradigms to avoid even the remotest unfortunate possibility of becoming marginalized and/or non-sustainable. New and innovative approaches are needed, and limiting the rethinking of their roles is not an option. More importantly, planning for the future, and what knowledge should be passed on to students are some of the key driving forces (Saguy, 2016). Consequently, *engineers of the*

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future will face bigger and more demanding challenges. Whereas *engineers of the past* mainly focused on the technical and economic feasibilities of systems design (Alwi et al., 2014), *engineers of the future* will have the additional responsibility of addressing entirely new topics and dimensions (e.g., innovation, partnerships, creativity, entrepreneurship, sustainability, economic environment, social responsibility, population growth and aging). Furthermore, food engineers will be faced with unique challenges and should play a proactive role in the innovation ecosystem. A multidisciplinary knowledge base, health and wellness, and food security are some of the key and paramount ingredients that should be included (Saguy, 2016). For instance, one such multidisciplinary illustration is Google's study on collecting information that includes: participants' entire genomes and their parents' genetic histories, as well as information on how they metabolize food, nutrients and drugs, how fast their hearts beat under stress and how chemical reactions change their genes' behaviors (Barr, 2014).

The above presents some of the rapidly evolving challenges faced by food engineers, for which they need to play a proactive role. It also calls for rethinking and transforming the domain to a vigorous, holistic and dynamic profession, which should strive to go beyond today's vision. Consequently, it highlights the need for new curricula to train both students and professors. This is a very exciting time for food engineers, who can—and should—expand their horizons by offering insights and playing a proactive and significant role in this endeavor (Saguy, 2016).

A survey carried out by the Institute of Food Technologists (IFT) Employment & Salary Survey Report conducted in 2013, 51% of the respondents said that intellectual stimulation was key to their job satisfaction, with job security (23%) coming in a distant second. The participants with specific food science job functions included only 2% FEs with the highest degrees earned (IFT, 2014).

FE surveys focusing on curricula and state of the profession are scarce. On the other hand, few examples could be drawn from chemical engineering (ChE). For instance, one survey included closed and open-ended questions to assess the perspectives of ChE students who were taught fluid mechanics and heat transfer concepts using both traditional classroom lecture and the new student-centered on paradigm for Cooperative Hands-on Active Problem-based Learning (CHAPL). The study indicated that CHAPL could differentially influence measures of significant learning and may be beneficial to enriching the learning experience (Hunsu et al., 2015). Actual conditions of the curriculum and career path of ChE field in specialized high school, and seeking for a curriculum improvement plan for activation by means of identity establishment of ChE field were also studied (Yi et al., 2015). The European ChE (EFCE) Working Party Education (WPE) seeking to identify effective educational solutions to meet the challenges caused by the rapid rate of change in technology and society world-wide utilized a 1994 WPE survey of curricula in EFCE universities to identify a first degree level core curriculum. The problem of how to adapt the discipline to meet technological and societal changes without losing its identity was addressed. Basic sciences, ChE science, integrated systems design and holistic thinking were emphasized as essential elements of the discipline. It was suggested that the impact of changes arising from industry, new technology and society has driven the ChE discipline to a point where it is now ripe for re-invention. It also highlighted the impact of rapid industrial, technological and societal changes on ChE education. Curriculum development, personal development and life-long learning as three important factors for educating chemical engineers for a successful future were identified (Gillette, 2001). Another survey was carried out in China that has the largest global population of ChE students. It included 2158 students/engineers from more than 20 countries regarding their educational and professional career satisfaction with their major in ChE. The Chinese students/engineers (33%) indicated that they were not satisfied with their ChE selection as their subject of study or discipline for professional career. The survey has attracted widespread attention among Chinese university professors of ChE focusing on the questions how to encourage and attract excellent high-school students to the exciting world of ChE science and technology, and the pivotal role that the discipline plays, and will play even more in the future (Jin and Cheng, 2011).

Evolution of the education needs and the necessary paradigm shifts needed for ChE education and recent and future trends that have been impacted by shifts in academic research and industry needs were reported. For instance, next paradigm is likely to be one involving the integration of multiscale and systems analysis. In addition, the importance of promoting innovation in the curriculum to support the creation of new products and processes and encouraging entrepreneurship among students in ChE (Varma and Grossmann, 2014). The similarity with FE status may indicate that the debate on future education needs, and the role of innovation and entrepreneurship are quite parallel.

Internet resources to reproduce aspects of more sophisticated customer-research techniques via modern web-based user research in new product development (NPD) are frequently utilized due to low cost and the ability to reach a wide audience in a cost-effective manner (Shekar and McIntyre, 2012). For instance, a web-based survey was developed to let consumers assess the use of meat substitutes in different dishes. The survey consisted of 38 key questions with subdivisions and was completed by 251 respondents (Elzerman et al., 2015).

The aforementioned reports clearly highlighted some of the paradigm shifts and educational innovation and other topics such as collaborative, multidisciplinary, entrepreneurial and creativity have attracted a lot of attention, and also warrant a similar attempt at FE. Hence, the overall aims of this study were to assess the status of FE education, positions and attitudes, to identify possible gaps, and to recommend (where needed) possible additional topics to be considered for future curriculum development. To avoid the confusion caused by multiple, different, and sometimes conflicting global educational standards and definitions, the FE definition used in this study was: "A person who has one or more formal degrees in FE (BSc, MSc, PhD, DSc), and/or an equivalent degree in another field, and whose job description includes/included FE activities."

2. Methodology

The methodology used in this manuscript consisted of a structured questionnaire that was designed based on information gathered from food science and FE specialists. This questionnaire was conducted through an online survey using Qualtrics© software (http://www.qualtrics.com/). Before the survey was written, the prime author completed the prerequisite course: Collaborative Institutional Training Initiative (CITI Program; https://www.citiprogram.org) and obtained Helsinki authorization from the Committee for the Use of Human Subjects in Research through The Robert H. Smith Faculty of Agriculture, Food and Environment of The Hebrew University of Jerusalem (file: AGHS/01.15). The questionnaire was pretested (but the data were not utilized in the final analysis) using a preselected sample ($n = 38$) of leading food engineers from academia and the food industry to ensure its consistency and to seek inputs on additional topics. The suggested recommendations were incorporated into the revised survey, and it was then distributed by e-mail to a very wide audience consisting of numerous organizations, people and geographical locations (see acknowledgments section for full details). The criterion for participation in the survey was: holding a formal FE degree (i.e., BSc, MSc, PhD, DSc) and/or an equivalent degree in another field, and holding or having held a job whose description has typical FE activities. The survey was completely anonymous and was open from the beginning of February until the end of March 2015.

Respondents were asked for their opinions about the importance of the main professional tasks of food engineers in the next decade, the FE curricula and requirements for the next generation of engineering education. Importance ranking was based on a 5-point Likert-type scale consisting of: 1 (strongly disagree), 2 (disagree), 3 (neither agree nor disagree), 4 (agree) and 5 (strongly agree). For graphic presentation, these values were transformed to −2 (strongly disagree), −1 (disagree), 0 (neither agree nor disagree), +1 (agree) and +2 (strongly agree). Rating scales such as Likert-type are very common in marketing research, customer-satisfaction studies, psychometrics, opinion surveys, and numerous other fields. Diverging stacked bar charts are recommended as the primary graphical display technique for Likert and related scales (Heiberger and Robbins, 2014; Robbins and Heiberger, 2011), and this approach was adopted herein. Apart from the professional questions, the questionnaire included demographic information, education level and geography, degree and field of study. The data were analyzed using Excel© spreadsheet and statistical analyses (t-test, ANOVA [LSD], performed on IBM SPSS version 22; http://www-01.ibm.com/software/analytics/spss/).

3. Results

3.1. Respondents' profile

The total number of respondents that started the questionnaire was 579. Of these, 494 (85.8%) replied positively to the survey's sole participation criterion, namely: “Do you hold a formal Food Engineering (FE) degree (BSc, MSc, PhD/DSc) and/or have an equivalent degree in another field and your job description has/had typical FE activities?” However, some of the respondents failed to address all of the points and consequently had several missing values, as they ignored or preferred not to answer some of the questions. Those with 3 or more missing values were omitted and excluded from the panel. This yielded 353 valid respondents for the panel. Although not specifically asked, based on respondents' IP addresses, 36 countries participated in the survey.

3.1.1. Demographics and education

Demographics data are presented in Table 1. The age grouping was quite similar, but not identical to that in the aforementioned IFT study (IFT, 2014). The difference was probably due to the international origin of the respondents in our study.

Respondents were asked to fill in their degrees in the various education categories provided. Each respondent had up to 5 options (BSc or equivalent, MSc, PhD/DSc, MBA and none). The respondents' total overall number of degrees was higher than that of the total panel, as selection of more than one degree was possible (Table 1). Respondents with no BSc or equivalent degree were excluded. The high number of respondents with PhD/DSc degrees clearly reflected the prominent number of academic respondents. It was quite surprising to find that the number of respondents with one or more formal FE degrees was quite low (206 out of 531; 38.8%). The breakdown of the different degrees held by the respondents with a formal FE degree is given in Table 1. The number of respondents with one or more formal FE degrees was 137 (out of 353 respondents; 38.8%). This surprisingly low number suggests that most respondents had an equivalent degree in another field but their job description had typical FE activities.

The recent IFT data (IFT, 2014) showed a different distribution of PhD, MSc and BSc degrees: 24, 34 and 38%, respectively. These values indicate that the FE respondents in our survey included a higher number of PhD/DSc. However, the overall trend was quite similar.

3.1.2. Academic organizations and positions

The overwhelming majority of the total academic respondents were from universities, followed by research institutes and graduate teaching and research institutes, undergraduate teaching and research institutes, and others (Table 2). The main positions of the academic respondents are given in Table 2.

3.1.3. Non-academic respondents

The distribution of the respondents with non-academic and industrial affiliations is listed in Table 3. It should be noted that some non-academic respondents preferred not to provide this info explaining the lower number of 117 vs. the 153 expected. The overwhelming majority of the industrial functions were: those with R&D/scientific/technical responsibility, followed by management (excluding sales & marketing) and consulting. It is also worth noting that among the R&D/scientific/technical group, the distribution of jobs was quite wide. It was surprising to see that the number of food engineers lagged behind food scientists/technologists. A possible explanation for this might be that some of the latter group's job descriptions probably also included FE activities.

In addition, some of the respondents held the position of vice

Table 1
Respondents’ demographics and education level.

	Frequency	%
Qualified respondents (the panel)	353	100.0
Gender	326	100.0
Male	204	62.6
Female	122	37.4
Age group (years)	326	100.0
20 to 35	102	31.3
36 to 50	97	29.8
51 to 65	92	28.2
Above 65	35	10.7
Education − general[a]	531	100.0
BSc	161	30.3
MSc	147	27.7
PhD/DSc	214	40.3
MBA	9	1.7
Education − formal FE[a]	206	100.0
BSc	73	35.4
MSc	72	35.0
PhD/DSc	61	29.6

[a] Some of the participants had more than one degree.

Table 2
Academic organizations and positions.

	Frequency	%
Academic/Research organizations	200	100.0
University	169	84.5
Research only institute	10	5.0
Graduate teaching & research institute	9	4.5
Undergraduate teaching & research institute	6	3.0
Graduate teaching only	3	1.5
Other education institutes	2	1.0
Undergraduate (teaching only) institute	1	0.5
Academic positions	200	100.0
Professor	71	35.5
Associate Professor	37	18.5
Assistant Professor	29	14.5
Research appointment (no teaching)	17	8.5
Lecturer/Instructor	16	8.0
Visiting/Adjunct Professor	1	0.5
No ranks institute	1	0.5
Others	28	14.0

Table 3
Respondents with non-academic affiliation.

	Frequency	%
R&D/Scientific/Technical	62	53.0
Management	18	15.4
Consulting	17	14.5
Government	9	7.7
Others	9	7.7
Sales & Marketing	1	0.9
Purchase	1	0.9
Total	117	100.0

president. Among the respondents affiliated with government, the three main functions were research, management/administrative and inspection (Table 3). However, the number of government respondents was too low to draw any conclusions.

3.1.4. Employment and experience

Table 4 lists the respondents' employment experience, time at their present employment and the number of employments in food-related jobs. Respondents' years of experience was distributed almost equally with some exceptions. For instance, those with more than 20 years of experience were the largest group, followed by those with 0 to 5 years. The other two groups were also well represented (Table 4). This clearly indicates that the survey reached the young and more mature FE audience. The IFT survey (IFT, 2014) showed relatively similar, but not identical values for professional years of experience: 0 to 5 (22%), 6 to 10 (14%), 11 to 20 (25%) and above 21 (40%). This could indicate that the distribution of FE experience found in this survey was not too different from that of the IFT survey's respondents.

In terms of time in the present employment, the largest group was 0 to 5 years and the second largest was more than 20 years (Table 4). The number of employments in food-related jobs showed that most of the respondents had been employed in 2 jobs, followed by those employed in 4 or more jobs (Table 4). This indicated that food engineers are mobile and tend to change jobs. The number of respondents with 1 employment was probably linked to limited years of experience.

3.1.5. Geographical distribution

Table 5 shows the geographical location in which the respondents received their education. The three main regions for BSc degrees were Western Europe, Asia/Middle East and Eastern Europe (Table 5). North America & Canada came in at fourth, probably due to the fact that a BSc degree in FE is not common there. However, when higher degrees (MSc, PhD/DSc and equivalents) were considered, the number of graduates from North America & Canada moved to first place, followed by Western Europe and Eastern Europe (Table 5). It is worth noting the participation of respondents from other geographical regions, including the Far East, Oceania and Africa. This clearly demonstrates that the survey had a global distribution, although the feedback from these regions was quite low.

Table 4
Food-related professional experience, time at present employment and number of employments in food-related jobs.

	Frequency	%
Professional food-related work experience (years)	326	100.0
0 to 5	83	25.5
6 to 10	52	16.0
11 to 20	63	19.3
More than 20	128	39.3
Time at present employer (years)	326	100.0
0 to 5	122	37.4
6 to 10	53	16.3
11 to 20	70	21.5
More than 20	81	24.8
Number of employments in food-related jobs	326	100.0
1	82	25.2
2	103	31.6
3	57	17.5
4 or more	84	25.8

3.1.6. Fields of graduation

Fig. 1 depicts the fields from which the various respondents graduated. It also highlights the various domains that participated in the survey. It is important to note that due to the survey's definition of FE, several other domains are represented. The four main domains were Food Science and Technology (FS/FT), FE, Agricultural Engineering and ChE. FS/FT for all degree levels (BSc, MSc and PhD/DSc) was equal to or ahead of FE. This is a significant finding, indicating that food scientists/food technologists, as well as the other fields tested, fulfill the role of food engineers in practice. This could also indicate that the role of food engineer is not very well defined; the lines become blurred, especially with FS/FT. This lack of a valid unique distinction between FE and the other domains indicates that a formal FE degree is not a prerequisite for fulfilling a food engineer's function. This topic is also important when considering accreditation issues, as discussed in section 3.5.

These data also show that food engineers at all degree levels tested made up only 17, 20 and 23% of the holders of BSc or equivalent, MSc and PhD/DSc degrees, respectively. The surprising finding that food engineers make up less than 25% of the practitioners satisfying the survey definition of FE clearly indicates that the FE domain is dominated by other fields and consequently, food engineers may have only a partial impact on the field. The conclusion that the FE domain is already hiring graduates from numerous other fields requires careful consideration. If this continues, FE could be facing marginalization.

Fig. 2 shows the distribution of respondents that hold a BSc degree in FE and continued their education for higher degrees. Not surprisingly, for a MSc degree ($n = 103$), FE led (33, 32.0%), followed by FS/FT (18, 17.5%). However, the real surprise here is that FE is losing its core (70, 68.0%): those with a BSc in FE who chose another field for their MSc studies. For those who hold a BSc degree in FE and continued their study toward a PhD/DSc ($n = 65$), the picture is quite similar. In this case, the highest proportion is again FE (20, 30.8%), followed by those who chose FS/FT (14, 21.5%). However, the overall picture is unsatisfactory, as 45 (69.2%) of those with a BSc in FE selected another field for their graduate PhD/DSc studies.

This overwhelming margin of more than two-thirds selected other domains for their higher education (MSc and PhD/DSc) is disappointing and the reasons for it should be further elucidated if the FE discipline is to stop this hemorrhage. It should be noted, however, that the graduates might have pursued a different domain for a myriad other reasons, and further study is therefore warranted. It is also quite possible that some of the graduates will return to their studies in FE after having gained some practical experience; the above selection may simply reflect their expanding spectrum of interests.

3.2. Curriculum of the FE discipline

Among the respondents (Table 6; $n = 349$), it is apparent that the status of the FE discipline as represented by its curriculum is not uniform. The largest number of respondents indicated that it is a “stand-alone curriculum starting at the undergraduate level,” followed by those indicating that it is should be “a part of another program” and those indicating that it should be “a part of the food

Table 5
Geographical distribution based on where the education was received.

	Frequency	%
Geographical distribution where first degree was received	306	100.0
No BSc or equivalent degree	20	6.5
North America & Canada	51	16.7
South America	41	13.4
Western Europe	73	23.9
Eastern Europe	57	18.6
Asia/Middle East	64	20.9
Far East	4	1.3
Oceania	3	1.0
Africa	13	4.2
Geographical distribution where > first degree was received	306	100.0
No higher than first degree	27	8.8
North America & Canada	83	27.1
South America	27	8.8
Western Europe	73	23.9
Eastern Europe	55	18.8
Asia/Middle East	29	9.5
Far East	5	1.6
Oceania	3	1.0
Africa	4	1.3

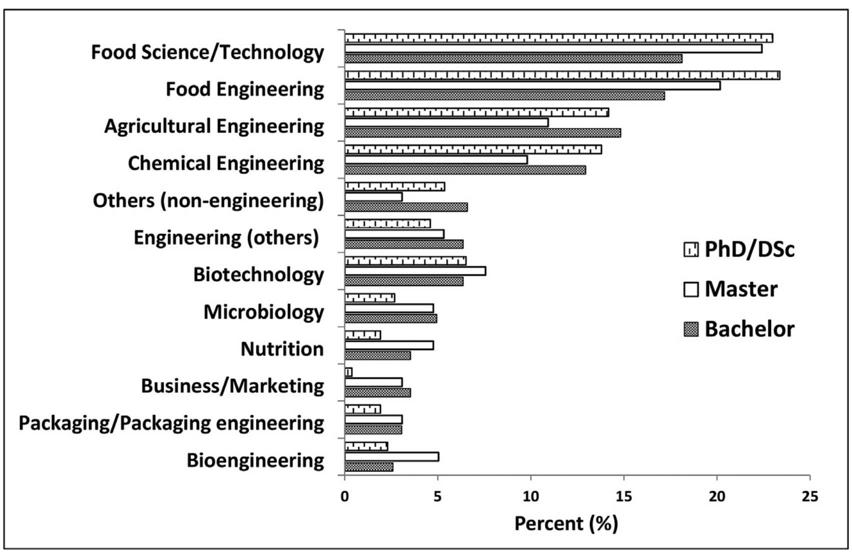

Fig. 1. Fields in which specified degree was received.

science program" (Table 6). Only 13.2% selected the "stand-alone curriculum starting at the graduate level." The latter is clearly the opposite of the common approach in the United States and should be considered for future planning.

Even more striking was that among all of the respondents holding a formal FE degree, only 57.7% indicated that the discipline should be stand-alone starting from the undergraduate level or graduate level, while the others indicated that it should be "part of another program" or "part of the food science program" (Table 6). This again suggests that food engineers are looking for possible changes in the discipline and considering other programs as probable acceptable alternatives.

Further analysis showed that this trend of FE should be a part of another program or a part of food science is even stronger among academia than industry (61.1 vs. 54.3%, respectively; Table 6). This could be interpreted as the overall respondents' dissatisfaction with the FE curriculum and it should be probably considered a warning for the profession and its future planning. Statistical analyses carried out on the data showed no significant differences ($p > 0.05$) among academia and non-academic respondents, further strengthening the overall conclusion.

3.3. Main professional tasks in FE

The main professional tasks in FE are depicted in Fig. 3. Common agreement was recorded among all of the respondents. Combining those that strongly agreed with those that agreed, "processing" was in first place (93%), followed by "applied research" (89%), "leading/participating in multidisciplinary teams" (87%) and "new product development" (NPD; 86%). Quite surprising was the much lower agreement on management (65%) and basic research (64%). On the other hand, combining "strongly disagree" with "disagree" yielded three groups with more than 10% of respondents, as follows: "basic research" (13%), "health & nutrition-related topics" (12%), and "information technology" (10%). These negative agreement probably indicate that some food engineers see basic research, health & nutrition-related topics and innovation technology topics outside of FE professional tasks.

It is important to highlight the obligations and opportunities of ChE in what was defined as unsustainable world. Namely,

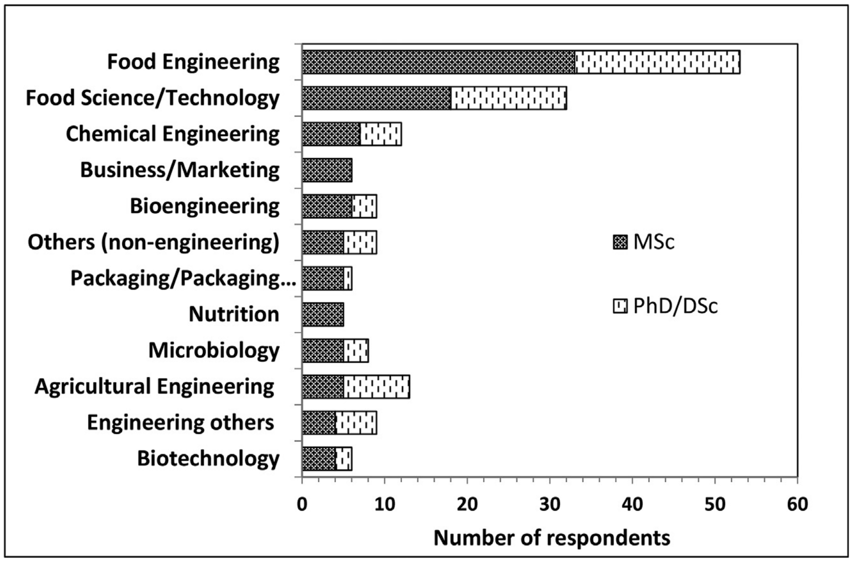

Fig. 2. Number of graduates holding a BSc in food engineering and continuing toward a MSc or PhD/DSc in various fields.

Table 6
Status of food engineering (FE) curriculum.

FE curriculum	Freq. (%)	Holding a formal FE degree Freq. (%)	Holding other degree Freq. (%)	Academia Freq. (%)	Industry Freq. (%)
Stand-alone starting at undergraduate level	105 (30.1%)	57 (41.6%)	48 (22.6%)	68 (30.6%)	37 (29.1%)
Stand-alone starting at graduate level	46 (13.2%)	22 (16.1%)	24 (11.3%)	25 (11.3%)	21 (16.5%)
As part of another program	104 (29.8%)	28 (20.4%)	76 (35.8%)	65 (32.2%)	39 (30.7%)
As part of food science program	94 (26.9%)	30 (21.9%)	64 (30.2%)	64 (28.9%)	30 (23.6%)
Total	349 (100.0%)	137 (39.2%)	212 (60.7%)	222 (63.6%)	127 (36.4%)

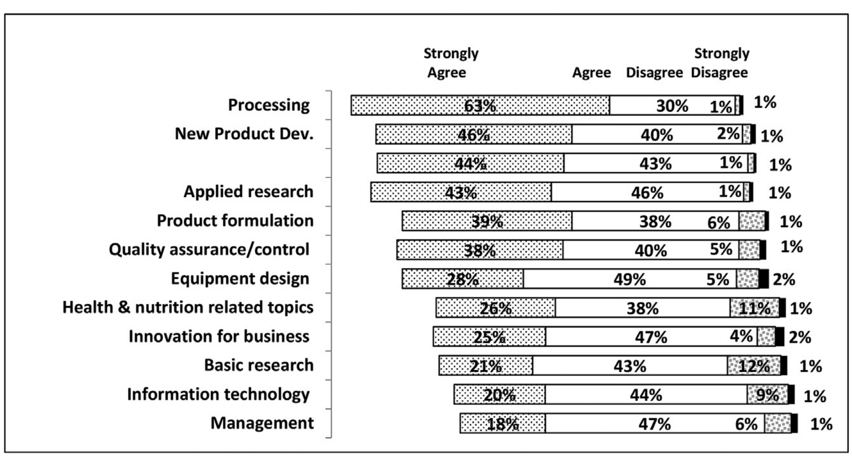

Fig. 3. Likert-type ranking of main professional tasks in food engineering.

technology alone is insufficient to meet the challenges at hand; ecological, social and economic considerations must be incorporated through a multi-faceted and multi-disciplinary approach. A new engineering paradigm is required therefore, whereby sustainability becomes the context of engineering practice. Chemical engineers also have a duty to engage and learn from other stakeholders (Byrne and Fitzpatrick, 2009). These important points should also be considered in FE future curricula discussions.

Analysis (t-test) of the academy vs. industry values showed significant differences ($p < 0.05$) only for "applied research," with academia's values being significantly higher. This could suggest that academia is interested in expanding their role beyond basic research to applied research in collaboration with the industry.

A weighted average of all of the food engineers' main professional tasks was calculated and the derived values are depicted in Fig. 4. Values between 1.0 and 2.0 indicate overall agreement ("agree" and "strongly agree"). The following topics were included in this category: processing, equipment design, NPD, multidisciplinary team and applied research. The weighted average also takes into consideration those expressing disagreement and/or strong disagreement. The data clearly showed that the following tasks were below the threshold value of 1.0: management, information technology, innovation for business, basic research, equipment design, and health and nutrition topics. These data could be interpreted as indicating that food engineers shy away from innovation and prefer traditional professional FE tasks. Further studies in designing future FE curricula are required to fully understand these worrying findings.

3.4. Comparison between FE and food science

A comparison was carried out between the FE and food science professions. The respondents (n = 348) were asked to rank FE against food science and food technology. The data projected a significant ratio of 2 to 1 (67% vs. 33%) of the respondents ranking FE higher. This is quite surprising because as outlined previously, food scientists/technologists were significantly represented in the survey.

In the next question, the respondents were asked to rank FE vs. food science programs in order of preference of the provided statements (from #1, most preferred to #7, least preferred). The weighted average was calculated (based on ranking #1: 7 points, #2: 6 points, … and #7: 1 point). The data are given in Table 7. The highest rankings overall and for academia were: "broader and better applied education that could be utilized in food and other fields" (#1) and "more innovative professions offering better entrepreneurship and broader activities" (#2). This order of importance was reversed for the industrial respondents. The difference between academia and industry was also quite clear for ranking #3, for instance, academia selected "better salaries and/or overall compensation," while industry selected: "more professional opportunities to serve the humanity." It is quite interesting to note the ranking discrepancy between academia and industry concerning "better higher salaries and/or overall compensation" (#3 vs. #5, respectively) probably indicating that for those working in the industry either the actual compensation is not high as expected, and/or that other topics are of greatest importance.

3.5. Competencies, harmonization, accreditation and regulated professional organizations

The weighted averages related to competencies, regulated professional organization, FE requirements, harmonization and accreditation using an importance scale from 1 (least important) to 5 (most important) were: standards specifying the FE core competencies, courses list and curricula are needed (4.03), become a member of a regulated Professional Engineering Organization (3.84), harmonization of courses to allow FE students to move between universities in the country (3.67), establishing FE requirements is needed to allow students to move between universities internationally (3.66), FE should strive for accreditation (3.60). Only "standards specifying FE core competencies, course lists and required curricula" scored above 4.0 (i.e., high importance). The lowest score was given to "FE should stride for

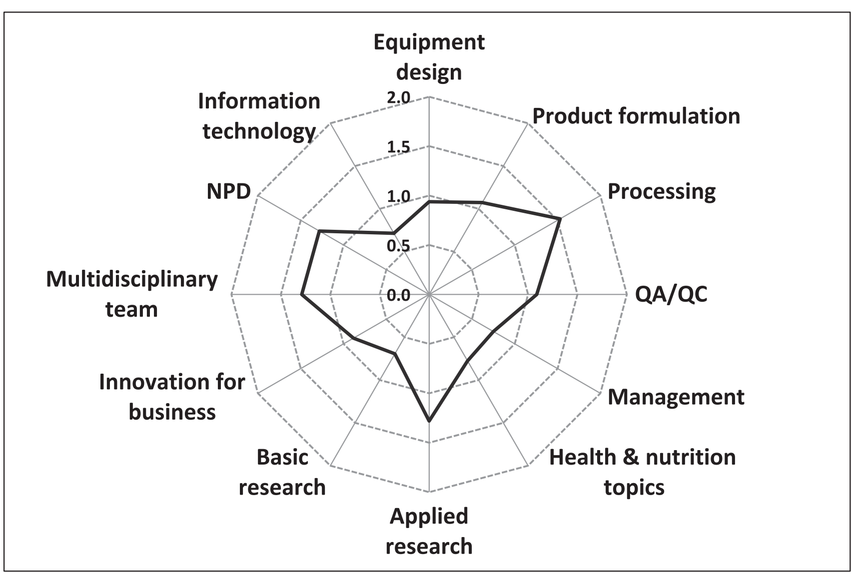

Fig. 4. Weighted averages of main professional tasks in food engineering (NPD, new product development; QA/QC, quality assurance/quality control).

Table 7
Ranking food engineering (FE) vs. food science (FS) program (weighted average).

Statement	Overall/academia	Industry
Broader/better applied education that could be utilized in food/other fields (n = 180)	#1	#2
More innovative profession offering better entrepreneurship & broader activities (n = 166)	#2	#1
Better salary and/or overall compensation (n = 184)	#3	#5
Better opportunities to obtain/maintain employability (n = 177)	#4	#4
More professional opportunities to serve humanity (n = 162)	#5	#3
Enhanced promotion potential (n = 183)	#6	#6
Better working conditions (n = 172)	#7	#7

accreditation." This is probably due to the fact that most of the respondents had a non-formal FE education, this topic may not considered viable and/or of great interest. Studies on FE accreditation are lacking. Accreditation of food science and technology degree programs were a part of ISEKI mission (https://www.iseki-food.net/accredidation/equas_food_award; accessed Nov. 14, 2015).

A hypothesis explaining the relatively low weighted averages obtained in some cases might be the difference between academia and industry. Indeed, statistical analyses yielded highly significant differences ($p < 0.01$) between academic and industrial respondents for, e.g., "Establishing FE requirements is needed to allow students to move between universities internationally," and "Standards specifying FE core competencies, course list & curricula are needed." Significant differences ($p < 0.05$) were also found for "FE should strive for accreditation." The discrepancy between academia and industry on these topics calls for reassessment of the harmonization and accreditation and also mandates better collaboration between industry and academia to define future common strategies and goals.

3.6. FE sustainability

Sustainability is a critical aspect of any domain, especially when addressing the issue in terms of the people practicing The FE profession. The weighted average calculated from the data collected yielded these values; "FE is a sustainable domain and will maintain its current roles in the future" (1.00). The other two options: "FE is a sustainable domain only when it becomes a part of food technology/food science" (0.33) and "FE is a sustainable domain only when it becomes a part of ChE and/or other established engineering program" (−0.16) raised significant objection. Statistical analysis showed no significant differences between academia and non-academic respondents. These data are a reassuring vote of confidence for the sustainability of FE among all of its practitioners.

To further study the effect of geographical region on perceived FE sustainability we selected respondents holding a BSc degree; statistical analyses (LSD) showed significant differences ($p < 0.05$) among all regions (North America & Canada, South America, Western Europe, Eastern Europe, Asia + Middle East, and others) concerning the statement: "FE is a sustainable domain only when it becomes a part of food technology/food science." North America & Canada (weight average: −0.22) was significantly different from Eastern Europe (+0.56; $p < 0.01$), Middle East + Asia (+0.52; $p < 0.01$) and Western Europe (+0.26; $p < 0.05$), but not South America (+0.02; $p > 0.05$). This signifies different perceived attitudes of FE sustainability among some of the geographical regions tested. When comparing only those holding a BSc in FE, significant differences ($p < 0.05$) were found between North America & Canada and Western Europe (weighted average of −0.22 vs. 0.26, respectively), and between Eastern Europe and Asia & Middle East ($p < 0.01$; 0.56 and 0.52, respectively). Further analysis of those holding a MSc in FE showed no significant differences.

These data probably suggest that those holding a BSc degree are less confident in the sustainability of the FE domain per se, and may also furnish an explanation for the high number of respondents who chose to graduate in other domains.

3.7. Curriculum changes

A list of 19 different suggested topics for the FE curriculum was provided and the respondents addressed them using the 5-point Likert scale. For comparison, the weighted average was calculated and is listed in Table 8. Values between 1.0 and 2.0 indicate that respondents agree to strongly agree, respectively. Only six topics were included in this range (Table 8). It is quite interesting to note that both industrial internships and international programs were included.

On the other hand, many other topics were not included, calling for additional assessment. Statistical analysis (t-test) showed that academic respondents rated "advanced computer programing and mathematics" significantly higher than did industry respondents ($p < 0.01$), while "legal aspects" was rated higher by the non-academic respondents than the academic ones ($p < 0.05$).

It is warranted to compare the above data with those obtained from polling Chemical Industry data on the relative importance of six ChE subareas (namely, i. unit operations, transport phenomena, thermodynamics, separation processes; ii. reaction engineering, catalysis, kinetics; iii. analysis, modeling, simulation, process control; iv. materials, surface science, v. polymers; biotechnology, medical and life sciences; and vi. nanotechnology and its application; Varma and Grossmann, 2014). It turned out that faculty growth in the different areas was almost opposite. For instance, biological engineering, which was rated as the second lowest area in importance, had seen the most significant increase in faculty size across the three ranks of professor (22%), associate professor (26%), and assistant professor (36%). In contrast, unit operations, regarded by industry as the most important area, saw a significant decrease in faculty size across all ranks, including professor (16%), associate

Table 8
Topics recommended for addition to food engineering (FE) curriculum (weighted average and standard error (SE); n = 351).

Topics	Weighted average	SE
Pilot plant & dedicated engineering labs	1.41	0.04
Industrial internships	1.41	0.04
Advanced engineering technology	1.33	0.04
Research internship	1.15	0.04
International programs	1.13	0.04
Creativity	1.03	0.05
Biotechnology	0.94	0.05
Advanced computer programming	0.85	0.05
Health, nutrition & well-being	0.82	0.05
Innovation related to firm's activities	0.78	0.04
Soft skills (e.g., human resources, communications, languages)	0.77	0.054
Management	0.71	0.04
Advanced mathematics	0.67	0.05
Legal aspects (e.g., business, law, intellectual property, patents)	0.66	0.05
Business and entrepreneurship	0.58	0.05
Social sciences (e.g., decision-making, ethics)	0.42	0.05
Marketing	0.34	0.05
Molecular biology	0.14	0.05
Medicine-related topics	0.07	0.05

Table 9
Requirements for the next generation of engineering educators (weighted average and standard error (SE); n = 345).

Attribute	Overall	Formal FE-degree ($n = 137$)	Non-FE degree ($n = 288$)	Significance
Engage career-long development programs in teaching and learning	1.03 (0.04)	1.14 (0.06)	0.96 (0.06)	**
Provide graduate students with opportunities in engineering education research	1.19 (0.04)	1.42 (0.05)	1.04 (0.06)	***
Encourage industry experience for faculty and future faculty	1.47 (0.03)	1.56 (0.05)	1.40 (0.05)	**

**Significant at p < 0.05.
***Significant at p < 0.01.

professor (12%), and assistant professor (6%). This highlights that disconnect between industry and academia is quite expected."

3.8. Next-generation engineering educators

Respondents agreed or strongly agreed (weighted average values between 1.0 and 2.0) with the statements concerning the next-generation engineering educators' needs. The derived overall weighted average was higher than 1.0 for all three statements in descending order: "Encourage industry experience for faculty and future faculty," "Provide graduate students with opportunities in engineering education research" and "Engage career-long development programs in teaching and learning." Statistical analysis showed a significantly higher difference ($p < 0.05$) between academia and industry only for "Provide graduate students with opportunities in engineering education research." When comparing those with a formal FE degree to those with a non-FE degree ($p < 0.05$) for "Engage career-long development programs in teaching and learning" and "Provide graduate students with opportunities in engineering education research," a significant difference was found ($p < 0.01$; Table 9). However, no regional differences were found.

3.9. Open topics

To gain further insights into the topics that contribute to a food engineer's success in the food industry, the respondents were asked to provide their comments in a free format. Topics that were identified at least four times by the respondents were (number of times in pretense): knowledge of industrial processing including process controls (16), knowledge of engineering fundamentals, skills and principles (12), innovation (9), food safety (6), food chemistry (4) food quality control (4), problem-solving skills (4), team work (4), communication skills (4) multidisciplinary vision (4) and management skills (4).

The responses highlighted the importance of engineering fundamentals in the food engineer's everyday work in the food industry. The underpinning knowledge of engineering subjects, including an understanding of mass and energy balances and approaches to designing experiments, was frequently cited. Innovation was another frequently mentioned topic, and it is clear that a food engineer's expertise in seeking innovative processes and NPD is important in framing a successful career. Several respondents noted a number of soft skills that a food engineer should possess, including creative approaches to problem-solving, participating in teamwork, strong communication skills, a multidisciplinary vision, and knowledge of management skills.

4. Conclusions

Some of the survey's main findings are listed here:

- The criterion for participation in the survey was: holding a formal FE degree (i.e., BSc, MSc, PhD, DSc), and/or having an equivalent degree in another field and holding (or having held) a job with typical FE activities in its description.
- The overall number of respondents with one or more formal FE degrees was 137 (38.8%; out of 353 respondents), holding 206 formal FE degrees (38.8% out of 531 total degrees), characterized as: BSc (73, 35.4%), MSc (72, 35.0%) and PhD/DSc (61, 29.6%). This surprisingly low number of FE degrees suggests that most respondents had an equivalent degree in another field but their job description included typical FE activities.
- Food engineers made up 17, 20 and 23% of the holders of a BSc degree or equivalent, MSc degree and PhD/DSc degree, respectively, who met the definition of the survey, clearly indicating that the FE domain is dominated by other fields and consequently, food engineers may have only a partial impact on the field. Hence, FE positions are already occupied by graduates from numerous other fields. This could lead to very severe consequences.
- More than two-thirds of the graduates holding a BSc in FE selected other domains for their higher education (MSc and PhD/DSc).
- Only 30.1% of the respondents indicated that FE is a "stand-alone curriculum starting at the undergraduate level" and an additional 13.2% selected the "stand-alone curriculum starting at the graduate level." Most indicated that it should be "part of other programs" and "part of the food science program" (29.8 and 26.9%, respectively).
- Overall, respondents preferred traditional topics for their future curricula and were somewhat innovation-shy.
- Main professional FE tasks selected by the respondents were: processing, equipment design, NPD, multidisciplinary team and applied research. On the other hand, management, information technology, innovation for business, basic research, equipment design and health and nutrition were given a lower preference.
- An overwhelming majority of the respondents (more than two-thirds) ranked the FE profession higher than food science.
- FE is at a crossroads and it should initiate a process of reassessment to decide on its vision and strategy to recapture its status and to stop the loss of its graduates to other fields.
- The survey indicates that this is a critical time for FE to make significant changes. It should rise to the mounting challenges by standing on the shoulders of its forerunners, and concurrently making paradigm shifts in its vision in the pursuit of excellence and innovation.
- Industry and academia research trends dictate special FE skills focusing on integration of nutrition, safety, materials science, modeling and innovation. These skills should address a plethora of future challenges such as human internal unit operations (e.g., digestibility, gastric aspects, targeting, bioavailability), health and wellness (e.g., medicine, brain, biology, biota, pro- and pre-biotics, nanotechnology, biotechnology), nutrition (e.g., personalization, prevention, satiety), modeling (e.g., virtualization, Internet of Things), food safety, consumer needs, expectations and protection and social responsibility.
- As there is no previous similar FE survey conducted, there may be other readings of the data. Hence, additional surveys are

warranted, focusing on increasing the number of respondents and a collaboration of several institutes representing the wide FE stakeholders. Hopefully, the information collected would open the necessary discussion to implement the identified gaps and the possible paradigm shifts required.

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