A possible reconceptualization of food engineering discipline

Version R2 (FBP-D-15-00556) April 2016

A Possible reconceptualization of Food Engineering discipline

Keshavan Niranjan

Department of Food and Nutritional Sciences, University of Reading, Whiteknights PO Box 226, Reading RG6 6AP (UK)

Abstract

Food industry is critical to any nation's health and well-being; it is also critical to the economic health of a nation, since it can typically constitute over a fifth of the nation's manufacturing GDP. Food Engineering is a discipline that ought to be at the heart of the food industry. Unfortunately, this discipline is not playing its rightful role today: engineering has been relegated to play the role of a service provider to the food industry, instead of it being a strategic driver for the very growth of the industry. This paper hypothesises that food engineering discipline, today, seems to be continuing the way it was in the last century, and has not risen to the challenges that it really faces. This paper therefore categorises the challenges as those being posed by: 1. Business dynamics, 2. Market forces, 3. Manufacturing environment and 4. Environmental Considerations, and finds the current scope and subject-knowledge competencies of food engineering to be inadequate in meeting these challenges. The paper identifies: a) health, b) environment and c) security as the three key drivers of the discipline, and proposes a new definition of food engineering. This definition requires food engineering to have a broader science base which includes biophysical, biochemical and health sciences, in addition to engineering sciences. This definition, in turn, leads to the discipline acquiring a new set of subject-knowledge competencies that is fit-for-purpose for this day and age, and hopefully for the foreseeable future. The possibility of this approach leading to the development of a higher education program in food engineering is demonstrated by adopting a theme based curriculum development with five core themes, supplemented by appropriate enabling and

knowledge integrating courses. At the heart of this theme based approach is an attempt to combine engineering of process and product in a purposeful way, termed here as *Food Product Realisation Engineering*. Finally, the paper also recommends future development of two possible niche specialisation programs in Nutrition and Functional Food Engineering and Gastronomic Engineering. It is hoped that this reconceptualization of the discipline will not only make it more purposeful for the food industry, but it will also make the subject more intellectually challenging and attract bright young minds to the discipline.

Highlights:

- Food engineering is not perceived to be a strategic driver of food business.
- A new definition and scope of food engineering as a discipline is presented.
- A theme-based approach to higher education curriculum design is also presented.

Keywords

Food Engineering; Issues and Challenges; New Definition; Competencies; Curriculum design

1. Introduction:

The discipline of Engineering – more than other disciplines – is constantly requiring to respond to a variety of demands, and continuously develop its educational programs by innovatively adapting its learning objectives and contents to the most recent findings in science and practice. But increasingly, engineering education is challenged by additional demands: 1) globalisation, which makes transferable skills and social competences of graduates much more important; 2) the focus on independent life-long-learning through professional practice and ICT based technologies; 3) societal demands relating to environmental, sustainability and ethical issues, whilst contributing to economic developments; and finally, 4) decreasing student enrolment into engineering programs (Heitmann, 2005). In addition, regional changes in educational framework in different parts of the world, such as the implementation of the Bologna protocol in the European Union, have set new goals for the whole higher education system; and engineering education has been compelled to respond by including provisions for harmonised quality assessment for university courses, introducing changes to teaching and learning methodologies, and developing frameworks for the exchange of students and academics. Thus, new approaches have been recommended in various engineering disciplines; e.g. Mechanical Engineering (Fernandes Teixeira et al, 2007), Electrical Engineering (Wilson et al, 2011), Civil Engineering (Murray and Tennant, 2014) and Chemical Engineering (Glassey et al, 2013). It is somewhat unfortunate that there are relatively few articles in published literature analysing food engineering education and training *per se*, and virtually no article which attempts to develop an educational program which responds to the challenges that food engineering discipline faces today. This article attempts to redress this situation.

Several attempts to review different facets of Food Engineering discipline have been made in the past, including the recent past. Saguy et al (2013) have attempted to cover a broad range of factors influencing food engineering and identified challenges and opportunities. The challenges addressed by these authors are essentially social challenges, such as world population growth, ageing, obesity, which have a broad vision span. Hence, the opportunities and solutions identified, although relevant to Food Engineering, are not exclusive to the discipline. The paper also gives an overview of Food Engineering education and makes recommendations on what more could be done to make the subject more relevant and responsive to our needs in the future. It may be noted that this paper is essentially based on the views and opinions expressed at a discussion session held during the Conference of Food Engineering 2012, in Leesburg, Virginia, USA. As a result, its narrative is somewhat fragmented and diffused, perhaps because it is more faithful to the discussion which took place, instead of addressing the subject in a sharp and concise manner. Nevertheless, this paper gives a very good snap shot of the range of views and opinions held by key academic and industrial personnel.

A range of authoritative views and opinions on Food Engineering can also be gained from the papers presented at the International Congress of Engineering and Food, ICEF8, presented as a compilation by Welti-Chanes et al (2002) under the sub-section title "Vision"; the authors in this section include such eminent names as Jowitt, Lund, Swartzel, Trystram and Bimbenet amongst others. Prior to this, Karel (1997) reviewed the history and future of Food Engineering; and Niranjan (1994a) and Holdsworth (1971) reflected on the links between Food and Chemical Engineering. There is no doubt that there are many other papers published on this subject, and this paper is not intended to be a critique of published narratives.

Like every other live discipline, Food Engineering is constantly evolving. But it would not be inaccurate to suggest that, until recently, the evolution of the subject, globally, has been more serendipitous. With progressively decreasing levels of funding, and increasing financial accountability, most developmental activities have had to be justified and prioritised against stipulated outcomes, which may have constrained the "natural" or "organic" evolution of the subject, but given it a sense of direction with identifiable key drivers . As in the case of all scientific disciplines relating to food, the key drivers for evolution in Food Engineering are: *health*, *environment* and *security*. These three drivers are not necessarily mutually exclusive, but discipline developmental activities can be conveniently organised under these three drivers, which also provide grounds for justifying any specific activity and enable resources being allocated to undertake the activity. Thus, the evolution of food engineering has undergone a major transition: it's growth is no longer "organic" or unconstrained with blue skies as the vision, but evidently steered by the three stated drivers. Given this philosophical transition which has occurred, it is time to take stalk of the situation and review the state of Food Engineering as a discipline. The main purpose of this paper is to reconceptualise what we mean by Food Engineering, so that: 1) we are able to meet the key challenges facing the practice of the discipline today, 2) identify subject-knowledge competencies of food engineering fit for this day and age, and 3) develop a framework for higher education programs to train food engineers of tomorrow.

2. Challenges facing food engineering:

Before embarking to reconceptualise the discipline, it would be worthwhile pausing to reflect upon the challenges facing the discipline in some detail. Of course, food engineering faces all the challenges which other engineering disciplines face, and these have already been mentioned in the opening paragraph and elegantly summarised by Heitmann (2005). In addition, food engineering also faces challenges which are of a societal nature, such as the water-energy-food security nexus (2014) and obesity, but these challenges cannot be tackled exclusively by the food engineering discipline, and require a concerted response from a number of disciplines. The rationale behind the selection of challenges facing food engineering discipline in this paper is based on: 1. its current status within higher educational establishments and 2. its changing role in industrial practice, both of which, the author believes, can be addressed by the discipline itself.

With regard to the status of Food Engineering within higher educational institutions, it is worth noting that there are relatively few countries where it is the norm for universities to have full-fledged food engineering departments on par with, say, mechanical, electrical, civil or chemical engineering departments. Brazil, Chile, Thailand and Turkey are examples of countries where food engineering has thrived under independent academic departments. In China, the discipline conducts itself within the so-called "food science and engineering" departments, whereas in India, food engineering is a part of agricultural engineering and more often than not taught in Agricultural Universities. It is worth noting that one of the main problems faced by Food Engineering discipline within higher educational institutions - especially in Europe, USA, Australia and New Zealand - is that the discipline is invariably run by other engineering departments, such as chemical engineering, mechanical engineering or biosystems engineering, and therefore considered to be their subsets. Food Engineering is inevitably perceived to be, and often conducted as an abridged version of another branch of engineering, which has not only thwarted its autonomous growth and development, but also discouraged recruitment of bright young minds into the discipline. Thus, the need to give Food Engineering discipline a strong identity of its own is an absolute imperative.

With regard to the challenges faced in the industrial practice of food engineering, Niranjan (2014) has addressed these as challenges posed by: *business dynamics*, *market forces*, the *manufacturing environment*, and *environmental considerations*.

2.1 Challenges posed by business dynamics

There has been an unprecedented change in manufacturing philosophy induced by international trade agreements which have allowed, virtually, barrier-less flow of materials (natural as well as processed) across national boundaries. This has opened up the opportunity for manufactures to set up production units in those countries where production costs can be kept as low as possible, trading raw materials and finished products right across the globe. Developed economies have, more or less, priced themselves out of contention in respect of manufacturing relatively low value products. As a direct consequence, the same state-of-the-art manufacturing methods - which were, in the past, associated exclusively with the developed world - are being employed all over the world, regardless of the economic state of the country or region where manufacturing is practised. The key consideration for manufacturers is whether the technology can be implemented cost effectively or not in any given place; and technologists/engineers are expected to rise up to this challenge. This is in total contrast to the view that prevailed, say, thirty odd years ago, when each economy was expected to practise manufacturing methods that were appropriate to, or compatible with, its socio-economic needs; e.g. adoption of low automation levels in highly populated economies. Given the relatively low shelf-life of foods in relation to other commodities, offshoring manufacture (Gander, 2006) - has been limited to those products which can endure travel and climatic changes, and yet offer adequate shelf stability. In addition to offshoring, manufacturers have, and indeed continue to outsource a number of processing operations under contract, so that they can downsize themselves and focus more on their own key functions in a highly specialised manner (Higgins, 2010). Although it is difficult to provide hard facts indicating the level of outsourcing in processed food manufacture, it is undoubtedly significant, especially if we consider products such as soft drinks, alcoholic drinks and confectionery. According to a survey conducted by the magazine "Food Engineering", way back in 2003 (Higgins, 2003), almost one in five manufacturers had already outsourced more than 50 percent of engineering operations, and more than 8 percent had outsourced energy management functions, while another 18 percent had outsourced 90-100 percent of their microbiological testing. Thus, offshoring (and its antonym: re-shoring) requires the core subject-knowledge competencies of Food Engineering to be harmonised across the world, while outsourcing requires the discipline to adapt its learning objectives and contents in a highly specialised way.

2.2 Challenges posed by market forces

The food market in each country has its own idiosyncrasies, but processors are invariably under pressure to keep manufacturing costs low, especially by retailers, even though commodity and labour prices are increasing. In such an environment, existing product lines can only contribute in a limited way to business profits, and market advantage can only be maintained by regular introduction of new products. Further these products have to be developed from concept through to manufacture and market introduction in a very short time, and also be priced competitively (Fuller, 2011). Professor Solke Bruin, in an address to the Institution of Chemical Engineers' Food and Drink Subject Group (Niranjan, 2004), reported that innovation time had dropped from being around ten years in the 1970s to two years at the start of this century. The innovation time is significantly lower now, which also demands the development of very strong brands to sustain product life cycle. Food Engineers, therefore, have to design manufacturing lines which run in short campaigns to produce a wide variety of products. Equipment designs must therefore offer a high degree of flexibility. At the same time, they must run at increased speed and output, and possess higher efficiency. Other design features must include improved product handling, greater accuracy, simpler control and more versatile handling capabilities. The use of multi-functionally designed equipment, especially reactors, is common in the chemical industry (Stitt, 2004), and it is desirable to exploit this concept fully in the context of food processing. Are training programs in food engineering imparting skills necessary to respond to the above challenges? Unfortunately, this is not the case.

Most importantly, there has been a paradigm shift in food processing, where the industry - which essentially aimed to add value to farm produce after the Second World War- is now consumer focussed. This has clearly moved manufacturing emphasis from *food preservation* towards *consumer-driven product development*. In terms of engineering, this has meant a clear shift from *process engineering* to *product engineering*. In other words, the starting point for process design is the consumers' or the markets' expectations of product attributes. This is subsequently translated into the physico-chemical properties, microstructures and health attributes, which the product and process designs aim for. As it stands, product and process engineering studies seem weakly coupled, and there is a crying need to make both food process and food product engineering mutually purposeful.

The involvement of food engineering in new product formulation and development is itself inadequate. More often than not, engineering is consulted after the product formulation and smaller scale trials have been completed and expected to deliver scaled up processes required to meet market demand. *Food engineering is not an auxiliary service in product development, but it is a highly strategic driver*. The time has come for food engineers to play a dominant role in new product development, and for food engineering discipline itself to take ownership of product development. This can only happen if the scope of the discipline is itself recalibrated to include nano and microstructural material sciences and metabolic health sciences. Thus, the science base of food engineering discipline must be broadened substantially to meet product development and formulation challenges.

Other market driven initiatives stem from consumers' increasing intolerance of product quality and service failures. Consumers are also concerned about the traceability of the ingredients used in any product, and the longer-term health implications of the levels at which these ingredients are used. The issue of *traceability* first came to the fore when health concerns associated with the use of genetically modified foods were raised. Traceability is taken to mean the path taken by a product as it goes through the food chain (Regattiery et al, 2007). Consumers demand technology which would enable them to trace the path taken by the food they consume. The manufacturers, on the other hand, require technology to link their produce to a path which provides "proof of origin". Although this is clearly a food engineering issue, the discipline has not yet taken ownership of such matters, and it is high time that the discipline reacts robustly.

2.3 Challenges posed by the manufacturing environment

The manufacturing environment is itself changing. Quality management systems are being driven to the factory floor. This means data acquisition and management tools have to be integrated with individual machines, and efficient communication has to be established across the whole process. Data emerges from many sources: measuring sensors, on-line inspection and monitoring systems, production scheduling, process stoppage analysis systems, and also from product tagging systems. It is necessary to access data, interpret them, and interact with the process at a number of different levels; this places significant emphasis on communication. The role of programmable logic controllers (PLC) which establish communication between machines, and human-machine interfaces (HMI) which have better diagnostic and communication capabilities, are brought to the fore. Process control systems will therefore play an increasingly important role in ensuring that plant machinery is performing to its full potential. Even formal plant-wide strategies for managing food hygiene (usually in the form of the Hazard Analysis Critical Control Points (HACCP) system) are available. Control technology can confirm, for instance, that ingredients have been checked, used in accordance with the required recipe, processed according to a standard operating procedure (SOP), correctly labelled, and delivered (Bravington, 2000). A number of issues such as HACCP and Quality management systems are already enshrined in regulations in a number of countries. Moreover, processors are themselves volunteering to comply with internationally accepted standards such as ISO, because such accreditation enhances their credibility and enables them to trade across international borders. All these compliance requirements will make the task of food engineers increasingly complex and place greater demand on their competence.

2.4 Challenges posed by environmental considerations

The high culture of consumerism within our societies has escalated the problem of waste because of the use of disposable goods. Processed food wastes constitute one of the largest fractions of municipal wastes these days. Manufacturing processes operating under strict quality control, and retailing under stringent sell-by date regulations, has resulted in the generation of large volumes of food and packaging wastes. The food industry is facing increasing pressure to reduce its environmental impact, both from consumers and regulators (Mishra et al, 2011).

Transferring food from the field to the plate involves a sophisticated production and supply chain, but for the purposes of waste production this can be simplified into three main steps: agriculture, food processors/manufacturers and the retail/commercial sector. Each of the sectors generates waste and wash water. Given the complexity of the food chain, environmental impacts can occur at various points in the chain, even for a single food product. It is therefore necessary to take a holistic systems-based approach to tackle the problem, and undertake life cycle analysis as an integral part of food engineering science.

Food processing wastes are multiphase systems with liquid wastes containing suspended solids, or solid wastes containing occluded water. The percentage waste - expressed in terms of the difference between the masses entering the plant and leaving it - is rather low, less than 4-5% in many cases (e.g. dairy processing plants). However, given the volumes involved, the overall impact on the environment can be significant (Niranjan, 1994b). The food industry is also one of the biggest consumers of water, which is also used very inefficiently. Engineers must therefore design and develop processes which minimise the production of wastes as well as the water and energy consumed. A report by WRAP (Waste & Resources Action Program, 2013) elucidates various aspects of reducing the use of minimising water consumption in the food industry. It may be noted that the energy costs associated with food processing is relatively low in many operations, around 10% of overall costs (Walshe, 1994). Therefore, there is little incentive to take measures which will reduce the overall energy consumed. However, one must not lose sight of the environmental impact (e.g. greenhouse effect) of consuming high levels of energy, even if this is affordable. Most governments have now made provision for a range of incentives, and indeed penalties, aimed at reducing the overall energy consumption. Engineering design cannot therefore consider process efficiencies independent of environmental issues as they have tended to do in the past.

The area of packaging wastes is yet another major environmental issue. Packaging is acknowledged to perform a number of useful functions, but the environmental legacy of packaging wastes is considerably high, and, in many cases, outweighs benefits. Both consumers and governments are exerting enormous pressure on processors to cut down on the amount of packaging used, and use biodegradable or even compostable materials. The key question is whether food engineering competence includes balancing the functionality of the packaging against its environmental impact after the product is consumed?

It is evident from the above discussion that Food Engineers will be dealing with transients all the time. These transients may result from changes in the business environment, the nature of market forces, the manufacturing environment, or environmental pressures. Food Engineers have to be better trained than ever to cope with such pressures, and equip themselves with skills which are, more often than not, excluded from university curricula at present. In a nutshell, Table 1 demonstrates the paradigm change in Food Engineering between the time the discipline began and now. In order to address the above challenges, there is a need to overhaul the very scope of Food Engineering discipline by expanding the science base that it relies upon, and changing the very mind-set that drives process engineering today. The following sections attempt to reconceptualise the discipline and redefine its core subject-knowledge competencies in a demonstrably viable manner.

3. Definition of Food Engineering and its Core Subject-knowledge Competencies:

Food Engineering, unfortunately, is not a universally understood term, and as Jowitt (2002) points out, it means little or nothing to most people. If the objective is to inform people, in general, the following will probably suffice: *Food Engineering is the branch of engineering that deals with the technology of large-scale food production*. Earle (1966) defined food engineering as the study of the processes that transform raw materials into finished products or preserved foods so that they can be kept for longer periods. According to Heldman and Lund (2011), one of the earliest definitions of Food Engineering, attributed to Parker, Harvey and Stateler in a book published in 1952, is that it is “concerned with the design, construction and operation of industrial processes and plants in which intentional and controlled changes in food materials are performed with due consideration to all economic aspects considered”. Heldman and Lund (2011), however, concluded that “Food Engineering is both the identification and creation of physical principles associated with foods and ingredients, and the application of the principles to the handling, storage, processing, packaging and distribution of consumer food products”. It is interesting to note that the former definition deals with practical aspects such as design, construction and operation, while the latter definition emphasises the “physical principles” underpinning the delivery of consumer food products. Food Engineering is neither exclusively about processes and operation; nor is it exclusively about the physical principles underlying such processes. The principles underpinning food engineering cover a number of enabling sciences other than physical sciences, such as health and environmental sciences, and even include subjects such as economics, psychology, law, and societal values and ethics! Thus, none of the definitions given above are wrong, but they are glaringly inadequate for scoping the discipline. A new definition, which not only addresses the above challenges, but also captures the essence of the discipline, is proposed here:

“*Food Engineering is the work of designing, formulating and manipulating food products which have desired sensory, satiety, health and well-being responses; and developing - across various operational scales - designs for the lowest environmental impact processing, packaging and storage systems capable of realising the products and attributes*.”

This definition of Food Engineering combines *process engineering* as well as *product engineering*. The outcome of process engineering is a desired product, while any desired product requires a competent process for it to be made. One without the other becomes redundant! *Food product engineering* is believed to include characterising the following with a view to formulate the product:

1. initial, transitional and final physico-chemical, textural and rheological features of the materials,
2. the structural features of food materials over various *scales of scrutiny*, from nano through to micro and bulk,
3. the safety and fitness of these products for human consumption,
4. the structural and biochemical disintegration of products during oral processing and in the rest of the GI tract, and finally,
5. the human sensory, satiety, and overall health and well-being responses.

Food process engineering, on the other hand, has traditionally included designing processes, equipment and machines to manipulate/transform food materials to meet output targets, starting from farm produce. Although this interpretation is not incorrect, it is necessary to recognise that, over the years, the analysis within process engineering science has been too generic and inadequately sensitive to the nature of products and formulations. For instance, the analysis of distillation and other unit operations in engineering – as expounded in many text books – remains the same regardless of whether it is to be applied to petroleum based products or to alcoholic beverages meant for human consumption. This legacy of chemical engineering has unfortunately been bequeathed to food process engineering, and the time has come to recognise that every aspect of food process engineering must aim to *realise* food products in terms of quality and health attributes as well as the quantities desired. Establishing an intimate link between process engineering and product characteristics, clearly requires a change in the mind-set, and it would be better to rename the engineering competencies required to formulate and produce food products as *food product realisation engineering*. By doing so, we make the study of process engineering much more purposeful; the product formulated is the end goal and the process is a means to realise this end. We will not restrict process engineering to a product-insensitive “unit operations” based design exercise, but expand its scope and convert it into an effective vehicle to realise products and meet production targets. We will also be better placed to address some of the idiosyncratic features of food products and processes, such as producing the same product despite significant regional and seasonal variability in starting materials or running the same set of equipment in short campaigns to produce a range of products.

However, food engineering, as conceptualised here, requires broader subject-knowledge competencies than just food product realisation engineering, although the latter will undoubtedly be a dominant subject-knowledge competency. Food engineers must possess competence in:

1. microbiological and chemical aspects of food safety, with an awareness
2. sensory, consumer and psychological aspects of food,
3. physico-chemical and metabolic phenomena occurring in the GI tract, and their health and well-being implications, and last but not the least,
4. assessing the environmental legacy of food.

All these core subject-knowledge competencies can be successfully cultivated if we are able to develop a fit-for-purpose approach to Food Engineering curriculum design. It is necessary to note that this paper is only addressing subject-knowledge competencies for food engineers; and not the core professional competencies *per se*. The latter set of competencies is much more generic, and sets professional standards - which are regulated in most countries. For instance, within UK, it is “The UK Standard for Professional Engineering Competence (UK-SPEC)”, which sets out the competence and commitment required for registration as a professional engineer, which lists “Knowledge and understanding” and “Design and development of processes, systems, services and products” as the first two of its five generic areas of competence; the others being: Responsibility, management or leadership, Communication and inter-personal skills, and Professional commitment (http://www.engc.org.uk/ukspec.aspx). Any accredited course in Food Engineering in UK will be assessed against all five areas of competencies, and educational institutions embarking upon accrediting food engineering courses will be expected to develop competency-based curriculum, just as a number of other branches of engineering have done in various countries [Witt et al (2006), Goel (2006), Edwards et al (2009), Kovaichelvan (2014)]

The next section presents a theme-based approach, which provides a framework or a roadmap for food engineering curriculum design, entirely based on the definition and the subject-knowledge competencies identified above.

4. A theme based approach to designing core food engineering curriculum:

Engineering programs are commonly structured to contain a number of courses. It may be noted that *program* here refers to the whole program of studies, whereas *course* refers to a unit of learning lasting, typically, a term or semester. Each course is content based, and focuses on first introducing the underlying theoretical concepts and then explore applications, initially at the concept level and then at a system level. The number of core courses in any program depends on the scope of the discipline. When a discipline inherently possesses a very broad scope – as Food Engineering is envisaged to possess in this paper – the number of courses inevitably becomes very large. When this happens, students and stakeholders fail to understand the importance of the linkages within and between courses, and instead, view the program as a series of disjointed and unrelated topics and courses. One way of mitigating such an effect is to take a theme based approach to curriculum design, which involves identifying themes that collectively encapsulate the scope and spirit of the discipline. Moreover, each theme comprises courses designed to highlight the continuous and connected nature of studying, which also helps to sustain and enhance the pedagogical focus. A theme based approach to curriculum design has been successfully implemented in other disciplines; e.g. Dermody (2004) and Bailey and Sercombe (2008). A new theme based approach to Food Science programs has recently been introduced at the University of Reading in October 2014.

The definition of food engineering presented here and the subject-knowledge competencies identified, lend themselves to the development of a core curriculum for a higher education program of studies built around themes. If we re-visit the above definition, it is clear that the themes must not only address product design methodology, but also the product's sensory, satiety, health and well-being attributes. In addition, the themes must also include design methodologies for environmentally sustainable processing, packaging and storage operations. Five core themes are therefore being proposed, which, between them, cover all the above aspects: 1) Food safety, quality, and formulation, 2) Food structural engineering and sensory analysis, 3) Food product realisation engineering, 4) Transport processes in GI tract, metabolism satiety and health and 5) Environmental impact, food sustainability and security. Given the considerable variation in student entry level qualifications across the world, it is necessary to have appropriate enabling courses which will provide the necessary foundation and lead students to these themes. Further, given the holistic nature of the discipline envisaged in this new definition and the inevitability of applying process and product design at a very systemic level, it is absolutely necessary to supplement the themes with *core knowledge synthesising or integrating courses, which illustrate and enable practical application.* Thus, the five core themes, together with appropriate enabling and knowledge synthesising courses, provide a framework for developing a core food engineering curriculum which is flexible, yet fit-for-purpose in the context of the values which an higher educational institution eschews. This model is schematically illustrated in Fig 1 as the *Food Engineering Edifice*. It is necessary to note that the Food Engineering Edifice only refers to the core subject-knowledge. This article does not intend to stipulate all the subject and topics that should be taught within a Food Engineering program. The number of courses within each theme and the course contents will depend on local interpretation and the institution's academic requirements. Each institution will have its own statements on the outcomes of its programs, which will be linked to the professional skills and competencies expected of its graduates. The Food Engineering Edifice, presented here in Fig 1, can be core to the subject-knowledge and understanding – which is only one of the key professional competencies.

It is also important to note that each of the five core themes is meant to be broadly inclusive and also lend itself to constructive multiple interpretations. There is no attempt to exclude any subject or topic which is deemed to enhance student learning experience. To give an illustration, if an institution wishes to include the study of omics within the food engineering program, it is possible to have a course, or courses, in foodomics (Capozzi and Bordoni, 2013) within core theme 4 which covers health and nutrition aspects in its broadest sense. Likewise, data science modelling and related analytics can either be a part of theme 2 or any other theme depending on the context in which it is being taught. Thus, the themes provide an open contextual architecture for courses to be imaginatively included.

4.1 The five core themes:

Table 2 lists the themes and their respective outcomes. It may be noted that the themes can, and are ideally meant to run across the different years of the program. Table 2 also lists examples of courses which will potentially cover the learning under each theme and deliver its outcomes.

Theme 1 deals with food safety and quality, which is covered very extensively in all food science or technology programs. Within Food Engineering, this theme will inform on the components of food and their interactions; it will also inform on microbial safety and how this can be practically achieved; and finally, it will also impart in-depth knowledge of the role of various ingredients in a formulated food product.

Theme 2 principally deals with food structure. The book edited by Aguilera and Lillford (2008) addressed this subject exhaustively under the title “Food Material Science”, and this book has been highly influential in promoting the view that the design and manufacture of food product is essentially the design and manufacture of food structure. This philosophical approach of virtually synonymising food product and food structure has made a profound contribution to the analysis of product design and manufacture, and it merits being a core theme in any food engineering curriculum. It is however important to recognise that any structural description depends on the scale of scrutiny, and a highly heterogeneous material such as food may not have a consistent description across the various scales of scrutiny, from bulk through to micro and nano scales. Any student of Food Engineering must be aware of such inconsistencies and ways to reconcile inconsistencies, and this competence becomes critical in an educational program. Of course, the primary objective of studying food structure is to be able to understand how the constituent components are arranged in space, so that such an assembly can be consistently and reproducibly manufactured, which in turn, will ensure that the properties and stability of the product are also consistent. Although one may be inclined to believe that food structural engineering is related to instrumentally determined food texture and rheology, which in turn can be linked to aspects of sensory analysis such as mouth-feel, such relations, if at all they exist for a given food, are extremely complex. The book by Aguilera and Stanley (1999) has explored this area in some depth. These authors note that instruments on the one hand are only capable of measuring one aspect of a complex set of mechanical property, whereas sensory response involves mental integration of multitude of stimuli. Thus the two responses are inherently different. Yet, the simplicity, reproducibility, and often the lower cost of instrumental texture measurements have led researchers to explore ways of reconciling the responses, and there are a number of papers published in this area [e.g. Martens and Thybo (2000), and Van Aken (2007)]. Thus, this core theme will not only help address structural engineering on various scales, but also its link with human sensory responses and related techniques which are inherently highly stochastic in nature.

Theme 3, i.e. *Product Realisation Engineering*, is at the heart food engineering, and its outcomes and possible courses are described in Table 2. This theme gives Food Engineering a strong identity, distinct from other branches of engineering, and it can also serve as a USP for promoting the program to potential university applicants. This theme imparts all key subject-knowledge competencies required by any business organsiation to conceptualise and launch a food product. It will also help analyse and monitor on-going production, and make recommendations for process/product improvement strategies. Since *Food Product Realisation Engineering* is a concept that is being introduced for the first time, it is worthwhile listing courses/sub-courses which can potentially illustrate this theme, and for further clarity, list the contents of each of the courses; please refer to Table 3. A program, which successfully delivers this theme, must emphasise the generic principles of food processing, but not stop with it. The program must elicit the sensitivity of the process to the materials that go through it, perhaps in the form of case studies, as effectively illustrated by Clark (2009). At its core, this theme clearly recognises that food processing involves a number of operations working in tandem. Hence, in addition to the study of individual processing operations, it also highlights the connection between various operations much more effectively, and gives the opportunity for the program to extend the analysis to an interacting cluster of processing operations, and to the whole plant as a unit - all aimed at producing a target product. The study under this theme therefore involves design and monitoring of individual equipment as well as the whole facility. At the same time, this theme also imparts the learner with a range of competencies in respect of products – not merely looking at the transformation of raw materials occurring within a plant, but examining the logistics and informatics of the whole supply chain as well as the product after exiting the plant. In fact, this theme also lends itself to performing environmental impact analysis effectively. In other words, this theme imparts learners with engineering competencies required for the whole of the food chain, and in this respect, it is proposing a step change in the scope of food engineering curriculum over current practice.

Theme 4 introduces a food engineer to what happens to the food after consumption. In a world where health is a key driver for growth in food business, it is absolutely essential that food engineering does not restrict its vision span between “the farm and the fork”. The analysis of the post consumption fate of food, especially its de-structuring in the GI tract (which will determine bio-accessibility, and through it, the bioavailability of nutrients), will not only inform its health impact, but also give an engineer valuable input for product design and formulation, which can also be adapted to deliver functional ingredients in targeted areas of the GI tract whilst preserving their integrity up stream. The engineering “tool kit” for analysing the passage of food and subsequent metabolism are already being developed. A “transport phenomena” based approach combining fluid momentum transfer, solid mechanics, bio-accessibility, mass transfer and energy transport, holds the promise of giving a uniquely food engineering identity to this theme (Spratt et al (2005), Tharakan et al 2010, Ferrua et al, 2010) . It may be noted that food de-structuring is also relevant from a sensory perspective (e.g. mouth-feel, flavour release, pleasure etc.), and in this sense, it can significantly influence themes 1, 2 and 3, in addition to theme 4.

Theme 5 covers environmental impact assessment and sustainability across the food chain, and covers food security as well. Although there is a tendency in engineering programs to focus primarily on environmental impact assessments of specific processing operations, it is time that we do not restrict ourselves to such a narrow scope. Issues relating to the exploitation of land, water, air and energy will become extremely critical in the next few decades, and food engineers will have to take a holistic view of the depletion of natural resources brought about by intensive food manufacture. This theme must therefore be delivered in such a way that food engineers gain competencies in such holistic issues as the food-water-energy nexus, and are able to collaborate effectively with other disciplines to solve the major environmental problems facing humanity. Environmental sustainability of food production and manufacture goes hand in hand with food security. Food supply will inevitably become less secure if environmental resources get unsustainably depleted. It must however be noted that the term “food security” has many facets, and different features are emphasised in different societies. For instance, in some societies, food security may refer to a stable and steady supply of food in the face of threats posed by terrorism or other environmental factors, whereas in certain others, it may refer to the right balance of nutrients being sustainably available. Regardless, a key competency in food engineering must be the awareness of such multiple interpretations and the role that this discipline can potentially play in assuring food security.

4.2 Core Enabling Courses: It is necessary to note that the courses realising the thematic outcomes, stated in Table 1, can only be delivered if the students already have a background in engineering science. The enabling courses must therefore include engineering science in addition to basic physical chemical and life sciences. For instance, basics of transport phenomena, and appropriate introductions to processing and separation operations, and process control, may have to be introduced very early in the program – possibly, even in the very first year – as is the current practice in many chemical engineering programs within United Kingdom. Thus, the science base of food engineering requires considerable strengthening under the proposals presented here. From the point of view of course delivery, it will become even more critical to adopt a range of imaginative learning methods - classroom, laboratory, computer and field based – so that an ambitious range of enabling courses prepare students adequately for thematic learning. Having said this, it is equally important to recognise that there is limited space to fit all courses in one program. At the end of the day, a combination of entry level knowledge and practicality will determine the volume and contents of enabling courses. It is, however, worth noting that enabling knowledge does not have to be gained solely through enabling courses, but involve various forms of active learning – which is now commonly employed in many engineering schools (De Graaff and Christensen, 2004). Moreover, theme based curricular design provides the opportunity for learners to pick up enabling knowledge "on the go" as they progress through the themes. For example, a number of concepts in biotechnology or material science can be picked up while going through themes 4 or 2, respectively. Although mathematical modelling has not been explicitly mentioned within the context of the theme structure, its role, and indeed the role of mathematics itself, continues to remain crucial in food engineering – just as it is, in any other branch of engineering. Mathematics will form a dominant component of enabling courses; and mathematical analysis and interpretation will dominate the courses covered under each theme. Although the application of mathematical modelling at a research level is very high in some food engineering literature – as illustrated by the works of Datta and his group [e.g. Rakesh and Datta (2013) and Thussu and Datta (2012)], or a recent PhD thesis (Smith, 2013)] - its scope within undergraduate and graduate programs requires rigorous review.

4.3 Core knowledge synthesising or integrating courses: In the real world, it is very unlikely that the themes will be applied individually. The success of any curriculum will critically depend on how well the students are able to integrate and synthesise the knowledge gained under each theme. Therefore the *integrating or knowledge synthesising courses* will play a key role in determining how well graduating students are trained to face up to the challenges posed by the real world! A substantial *New Product Design and Process Development* exercise – which takes a student through the various stages – seems imperative in such a program. *Case studies* and related analyses can also be highly illustrative of knowledge integration across the various themes. Of course, an appropriate *Industrial Placement or Internship* can prove to be invaluable in this respect. It must be noted that knowledge synthesis across the themes must be embedded in the very culture of course delivery, right from the start of thematic learning. Whether, at present, this is happening effectively across various courses within a program is arguable. Thematic learning will lend itself to the development of integrating topics and problems, and enhance student learning experience.

5. Interpretation of themes within Food Science and Technology programs and possible specialised Food Engineering related programs for future development:

The themes listed in Fig 1 and described in Table 1 are also relevant to Food Science and Technology programs. But the main difference would lie in the emphasis on "design". While food engineers are distinguished by their ability to design and construct products, structures and processes, food scientists and technologists may have an informed awareness of design aspects. The competence of Food Scientists has historically revolved around product formulation, product quality, product safety and sensory aspects, whereas the competence of Food Technologists has been around process plant operation and management. Over the years, these distinctions have got blurred and it is not uncommon to find the two disciplines competing for the same jobs in industry. Regardless, food engineering has been historically taught in food science and technology programs at various levels depending on the objectives of the program and the institutions. It would be desirable to select courses from each theme for wholesome development. Since the themed structure presented here offers curricular flexibility, it enables course designers to make an informed choice of courses and contents.

While the themed structure presented in this paper gives food engineering its much needed rigour and relevance in the 21st century, it is also necessary to make it as well known in the society as other branches of engineering such as mechanical, electrical or civil engineering. Therefore, in addition to all the methods that one uses to popularise engineering disciplines, it would also be helpful to link food engineering robustly with two branches of food science which are receiving very high media attention: nutrition and gastronomy. Needless to say, this paper is not attempting to seek cheap popularity for the food engineering by linking it with nutrition and gastronomy. As the following paragraphs will illustrate, there are considerable academic and practical merits of linking these disciplines.

Nutritional science is developing at a very rapid pace, but its emphasis is not merely restricted to the study of basic micro and macronutrients, and their role in shaping human health. Instead, this branch of science has expanded its scope to include the relationship between diet and disease, such as the influence of food and food components on cardiac, gut and neurological health. More importantly, this branch of science also includes the study of how appropriate dietary interventions can be used to prevent diseases from taking root in human body. Thus, nutritional science is considering health effects of food that is way beyond basic nutrition, and a recently developed subject area addressing this issue is commonly referred to as *functional food science*. Thus, functional food science specifically addresses the effects of whole foods, and food components, on the health and function of specific organs as well as the whole body. There is no doubt that food engineering has a critical role to play in the development of such products. Food Engineering input is also required in process design and development that will deliver products on a scale that can benefit the whole society. Thus, a specialised area of food engineering – possibly termed as *Nutrition and functional food engineering* - will be its application to nutrition and functional food areas, which will play a major role in whole populations benefiting from research which currently relates either to laboratory scale or a small sample of population. This course will require learners to have a general level of competence in all core themes, but will involve specialisation in theme 4. This example illustrates how the themed structure lends itself to curricular flexibility which enables learners to be "generalists" in all five core themes, but specialise in one theme (T shape) or two of the themes (Π shape) or more than two themes (comb shape!)

Yet another niche area of food engineering can be its application to cooking, particularly to gourmet cooking which is essentially an artisan activity. This branch of food engineering has been termed *gastronomic engineering* by Aguilera (2009). Cooking is essentially an art, and gourmet cooking is a skill restricted to a relatively small number of individuals. Bringing to bear upon cooking, core food engineering competencies, will have two positive effects: 1. the stated competencies will increase the range of products produced in kitchens (this is already happening in the form of "molecular gastronomy" where customers in certain restaurants are treated to novel products, tastes and eating experiences; and 2. the stated competencies will also enhance the access of the population to gourmet foods. To an extent, the latter is also already happening, for instance, in machines such as Nespresso™ or Tassimo™ where gourmet hot beverages – so far made almost exclusively by gourmet baristas - can now be made very affordably in normal kitchens. It is interesting to note that these machines do not merely involve hardware, but the hardware only performs when ingredients and their containers are specially adapted to it. Thus, a high level of compatibility is established, right at the design stage, between ingredients and their quality and quantities on the one hand, and the hardware itself on the other. Indeed, in such devices, *gastronomic engineering* will assure a clear and consistently reproducible link established between raw material parameters, machine operational parameters and the product quality attributes – which is the paradigm that food engineers strive to achieve in every process. Thus, *gastronomic engineering* - defined as *the application of engineering science to produce personalized gastronomic products* - can be a valuable specialism within food engineering.

6. Conclusions:

1. This paper identifies key challenges facing food engineering discipline and presents a new definition of food engineering which is aimed at making the discipline fit-for-purpose for this day and age. The definition puts the food product - and its health and environmental impact - at the heart of the discipline, and leads rationally to identifying its core competencies.
2. The paper also recommends a theme based curriculum development for higher educational institutions wishing to deliver programs in this subject, and identifies five specific themes which lend themselves to program development with targeted subject-knowledge

outcomes. The study of these themes must be supplemented with appropriate enabling courses and theme integrating courses.

3. At the core of this theme based approach is an attempt to combine engineering of process and product in a purposeful way which treats the product as the ultimate goal and the process as a means of achieving this goal; the combination of process and product engineering is termed here as “Food Product Realisation Engineering”.
4. Finally, the paper also recommends future development of two possible advanced specialisation programs in Nutrition and Functional Food Engineering and Gastronomic Engineering, which, along with the reconceptualization of food engineering as described in this paper, will produce bespoke engineering graduates for the food industry.

Acknowledgments:

The author wishes to acknowledge all his peers with whom he has held various discussions from time to time, which have helped him considerably to formulate the views and opinions expressed in this paper. The author is particularly grateful to Dr Geoff Andrews, formerly of Northern Foods, for sharing his presentation on identifying the engineering challenges facing food industry, which forms the basis of Section 2 of this paper; and to Mr Doug Marriott of Doug Marriott Associates Ltd for communicating his views on the current state of engineering in food business.

References:

Aguilera, J.M. and Stanley, D.W. (1999) Microstructural principles of Food Processing and Engineering. Aspen Publications (Gaithersburg) p.252.

Aguilera, J.M. and Lillford, P.J. (2008) (Editors) Food Material Sciences: Principles and Practice. Springer.

Aguilera, J.M. (2009) Gastronomic Engineering. In "An Integrated Approach to Food Product Development" Moskowitz, H.R., Saguy, I.S. and Straus, T. (Editors) CRC Press, pp 317-328.

Bailey, R and Sercombe, P (2008) Adjusting the paradigm: A theme-based approach to pre-sessional EAP in a British University. *The Buckingham Journal of Language and Linguistics*, **1,** 1-20.

Capozzi, F and Bordoni, A (2013) *Foodomics*: a new comprehensive approach to food and nutrition. *Genes Nutr.* **8**(1): 1–4.

Clark, J.P (2009) Case Studies in Food Engineering: Learning from experience. Springer.

De Graaff, E. and Christensen, H.P. (2004) Editorial: Theme issue on active learning in engineering education, *European Journal of Engineering Education*, **29**:4, 461-463.

Dermody, B. (2004) Improving Student Learning Through Theme Based Curriculum Design and Team Teaching: An Action Research Study. MA Dissertation, Dublin Institute of Technology, Dublin.

Earle, R.L. (1966) Unit Operations in Food Processing, Pergamon (London).

Edwards, M., Sánchez-Ruiz, L.M. and Sánchez-Díaz, C. (2009) Achieving Competence-Based Curriculum In Engineering Education In Spain. INGENIO (CSIC-UPV) Working Paper Series 2009/04 pp 1-25. (http://digital.csic.es/bitstream/10261/14228/1/Achieving_competence-based_curriculum_in_Engineering_Education_in_Spain[1].pdf)

Fernandes Teixeira, J.C., Ferreira da Silva, J. and Flores, P. (2007) Development of mechanical engineering curricula at the University of Minho. European Journal of Engineering Education **32**(5), 539–549.

Ferrua, M.J., and Singh, R.P. (2010): Modeling the fluid dynamics in a human stomach to gain insight of food digestion. *Journal of Food Science*, **75** (7): R151-R162.

Fuller, G W. (2011) Food Product Development from Concept to Marketplace. 3rd Edition. CRC Press (London)

Gander, P (2006) Offshoring-puts-UK-supply-chain-at-risk-says-report. http://www.foodmanufacture.co.uk/Packaging/Offshoring-puts-UK-supply-chain-at-risk-says-report

Glassey, J, Novakovic, K. and Parr, M. (2013) Enquiry based learning in chemical engineering curriculum supported by computer aided delivery. *Education for Chemical Engineers* **8**(3), e87–e93

Goel, S. (2006) Competency Focused Engineering Education with Reference to IT Related Disciplines. *Journal of Information Technology Education* **5**, 27-52.

Heitmann, G. (2005) Challenges of engineering education and curriculum development in the context of the Bologna process. *European Journal of Engineering Education*, 30(4), 447-458.

Heldman, D.R. and Lund, D.B. (2011). The beginning, current and future of food engineering: A perspective. In Food Engineering Interfaces (Editors: J.M.Aguilera, G.V.Barbosa Canovas, R.Simpson, J.Welti-Chanes and D.Bermudez-Aguirre), Springer Food Engineering Series, pp 3-18.

Higgins, K.T. (2010) Outsourcing Engineering. *Food Engineering* (1 February, 2010) http://www.foodengineeringmag.com/articles/87539-outsourcing-engineering-1

Higgins, K.T. (2003) The case for outsourcing. *Food Engineering* (28 March 2003) http://www.foodengineeringmag.com/articles/82654-the-case-for-outsourcing

Holdsworth, S.D. (1971) Chemical engineering and food preservation research, trends and reflections. Chemistry and Industry, **1**, 16-24.

Jowitt, R (2002) International Congress on Engineering and Food: The first 25 years. In Welti-Chanes, J; Barbosa-Canovas, G.V.; Aguilera, J.M. (Eds.) (2002) Engineering and Food for the 21st Century, CRC Press, pp 57-63.

Karel, M. (1997) The history and future of food engineering. In: Fito, P., Ortega-Rodriguez, E., Barbosa-Canovas, G.V. (Eds.), Food Engineering 2000, pp. 3–19.

Kovaichelvan, V. (2014) Competency based Engineering Education. *International Journal of Indian Culture and Management* **8**(2) 253-273.

Martens H.J. and Thybo, A.K. (2000) An Integrated Microstructural, Sensory and Instrumental Approach to Describe Potato Texture. *LWT - Food Science and Technology* **33** (7), 471-482.

Mishra, N., Aal Bakr, A.A., Niranjan, K. and Tucker, G. (2011) Environmental Aspects of Food Processing. Editors J G Brennan and A.S. Grandison pp 571-591.(Wiley).

Murray, M. and Tennant, S. (2014) New Civil Engineer: introducing undergraduate civil engineers to construction technology. *Engineering Education* **9**(1), 33-47.

Niranjan, K. (1994a) Chemical Engineering Principles and Food Processing. *Trends in Food Science and Technology*, **5**(1), 20 – 23.

Niranjan, K (1994b) Food Processing Wastes: Their Characteristics and an assessment of processing options. In Environmentally responsible food processing. AIChE Symposium Series No. 300, 90 (Editors: K.Niranjan, M.R. Okos and M.Rankowitz) pp. 1 -7.

Niranjan, K. (2004) Conference Report, *Transactions of the institution of chemical engineers* Part C. **82**, 255-256.

Niranjan, K (2014) Challenges facing postharvest agro-industrial business: a view of the West. http://www.ipht.lk/Pro%20section%2001.pdf

Rakesh, V. and A. K. Datta 2013. Transport in deformable hygroscopic porous media during microwave puffing. *American Institute of Chemical Engineers Journal*, **59**(1):2013:33–45.

Regattieri, A., Gamberi, M. and Manzini, R. (2007) Traceability of food products: General framework and experimental evidence. *Journal of Food Engineering* **81**(2), 347–356.

Saguy, I.S.; Singh, R.P.; Johnson, T.; Fryer, P.J. and Sastry, S.K. (2013) Challenges facing food industry. *Journal of Food Engineering*, **119**(2), 332-342.

Smith, N.A.S. (2013) Mathematical models in Food Engineering. PhD thesis. Universidad Complutense de Madrid.

Spratt, P., Nicolella, C. and Pyle, D.L. (2005): An engineering model of the human colon. *Transactions of IChemE*, Part C, **83** (C2): 147-157.

Stitt, E H (2004) Multifunctional reactors? “Up to a point Lord Copper”, *Chemical engineering research and design*, **82**, 129–139.

Tharakan, A., Norton, I.T., Fryer, P.J. and Bakalis, S. (2010): Mass transfer and nutrient absorption in a simulated model of small intestine*. Journal of Food science*, **75** (6), E339-E346.

The water, Energy and Food Security Nexus (2014) http://www.water-energy-food.org/.

Thussu, S. and A. K. Datta 2012. Texture prediction during deep frying: A mechanistic approach. *Journal of Food Engineering*, **108**:111–121.

Van Aken, G.A. (2007) Relating food microstructure to sensory quality. In Understanding and Controlling the microstructure of complex foods (Edited by D.J.McClements) Woodhead Publishing Ltd (Cambridge) pp 449-482.

Walshe, N. M. A. (1994) Energy conservation and the cost benefits to the food industry. in Food Industry and the Environment, J. M. Dalzell, (Ed.), Blackie Academic & Professional, Glasgow, pp. 76-105.

Water Minimisation in the Food and Drink Industry (2013). WARP report. http://www.wrap.org.uk/sites/files/wrap/Water%20Minimisation%20in%20FD%20Industry.pdf

Welti-Chanes, J; Barbosa-Canovas, G.V.; Aguilera, J.M. (Eds.) (2002) Engineering and Food for the 21st Century, CRC Press.

Wilson, R., Georgakisa, S. and Hu, X. (2011) Meeting the Challenges of Electrical Engineering Service Courses. Australasian Journal of Engineering Education, **17**(2), 91-100.

Witt, H-J, Alabart, J.R., Giralt, F., Herrero J., Vernis, L and Medir, M (2006) A Competency-Based Educational Model in a Chemical Engineering School. *Int. J. Engng Ed.* **22**(2) pp. 218-235.

Table 1 - The changing focus of food engineering

Past focus	**Present focus**
Farm-facing	Consumer facing
Food preservation	Food quality, health and well being
Process Engineering	Product Engineering

Table 2 - The five themes of Food Engineering

Theme	Key Learning Outcomes	Possible Courses/sub-courses
1) Food safety, quality and formulation	a) To gain understanding of composition, properties, keeping quality and micro and macro nutrients of natural and formulated foods; b) To know the role of water and other ingredients in formulated foods and the effects of processing on their individual properties, as well as in combination with other ingredients; c) To gain in-depth knowledge of the microbial aspects of food safety, especially the quantitative aspects of microbial growth and death under various conditions; d) To learn about the techniques used in food chemistry and analysis, and be aware of the sources of adulteration and loss of chemical safety; e) To be able to design food formulations based on an understanding of the above.	Food chemistry and analysis; Food microbiology and safety; Food Physics; Water in food; Food ingredients; Product formulation engineering; Food composition and human nutrition.
2) Food structural engineering and sensory analysis	a) To appreciate the concept of scale of scrutiny and investigate techniques to visualize and analyze food structures across various scales of scrutiny, from nano, through to micro and bulk scale, recognizing the inherently multi-phase and multicomponent natures of foods; b) To conceptualize and quantify food texture, rheology, mouth-feel and other sensory properties of foods; c) To establish relationships between the properties mentioned in b) and food structure characterized across the different scales of scrutiny; d) To understand the linkages between food structure, and the location and composition of water and other ingredients within the structure; e) To be aware of techniques used to characterize structure and composition of interfaces present in food structures, and relate these to the stability of the structure; f) To acquire knowledge of experimental and statistical techniques and methodologies used in sensory analysis and consumer sciences.	Food Texture and rheology; Food structure, microstructure and nanostructure; Food emulsions, foams and stabilizing agents; Experimental and statistical methods in sensory analysis and consumer science
3) Food product realization engineering	a) To be able to draw up a clear statement of requirements for products and processes; b) To define/characterize safe and hygienic designs for recipe, process and packaging formats for a given product concept; c) To be able to apply HACCP system for food safety management and use Good Manufacturing Practice (GMP) and Prerequisite Programs (PRPs) to control the product manufacturing environment; d) To understand engineering factors influencing hygienic equipment design and operation, and embed these within the manufacturing environment; e) To identify product processing stages for a given product, and design individual processes, as well as the overall manufacturing outfit;	Product manufacturing design; Food packaging; Plant and Equipment Operations Management; Design and Control of safety in food manufacture; Design and control of hygiene in food manufacture; Supply chain and food distribution; Economic Viability Analysis and Project

	f) To be able to measure, control and assess individual equipment, and the overall plant operational performances, and implement performance improvement measures; g) To be able to analyze and assess logistics and informatics relating to supply chain for ingredients as well as traceability, and do the same for downstream distribution; h) To gain sufficient background knowledge of Process Economics in order to assess the economic viability of the project, and be able to chalk out project management pathway using tools like Critical Path method; i) To assess the environmental impact of the production facility as well as the environmental lifecycle of products and packaging from cradle to death;	Management (Possible contents of each of these courses are given in Table 3)
4) Transport processes in GI tract, metabolism satiety and health	a) To be able to demonstrate an in-depth understanding and critical awareness of: i) the physical and biochemical conversions taking place in the mouth and the rest of the GI Tract, with particular focus on the modelling aspects of the transport phenomena occurring in the stomach and intestines ii) micro and macro nutrient metabolism in various sections of the GI tract with particular focus on bioavailability of nutrients iii) the concept of satiety and practical methods used to measure satiety iv) the link between food components and cardiac health, gut health, neurological health and ageing; b) To be able to design targeted delivery systems for functional food ingredients.	Transport processes in GI tract; Nutrition, Bioavailability and Food Metabolism; Design, delivery and action of functional foods; Elements of Food Psychology.
5) Environmental impact, food sustainability and security	a) To be able to assess the environmental impact of i) primary food production and ii) food product manufacture (including packaging); b) To develop strategies and methods to mitigate the environmental impact of the processes used in food production; c) To develop an understanding of the design of water supply, waste water, solid waste and air quality handling facilities; d) To construct and analyze life cycle analysis (LCA) and Carbon foot printing reports; e) To construct energy management reports around: i) heating and refrigeration systems and other services, and ii) individual process equipment and overall process plants; f) To appreciate sustainability in relation to the management of soil, water and agricultural intensification; g) To gain a solid understanding of food security, its various interpretations and its links to the state of the economy – particularly focusing on the drivers behind poverty and food insecurity; h) To appreciate economic, legal, social and ethical aspects of food security and related environmental challenges.	Food production, processing and the environment; Energy and Waste management in the food industry; Sustainable soil, water and intensified agricultural production; Food Security.

Table 3 - Contents of possible Food Product Realization Engineering courses

Courses/Subcourses	Contents
Product manufacturing design	Development of flow sheet, design specification of individual equipment; Plant layout with particular emphasis on containment requirements; Design and control of storage systems for ingredients and products; Plant utilities and support facilities; Automation, Robotics, Instrumentation and process control.
Food packaging	Functions of food packaging in relation to product; Packaging materials and permitted food contact surfaces; Packaging for in-container processing and post-processing filling; Integrating packaging and filling systems within manufacturing design; Labelling, printing and decoration; Market drivers influencing packaging (product life cycle, product differentiation, customisation and versioning, etc); Environmental issues relating to packaging including recycle, re-use and end of use disposal.
Plant and Equipment Operations Management	Process Scheduling; Methodologies for analysing the performance of individual equipment and the manufacturing plant (Availability of equipment/plant, Performance of equipment/plant, Overall Equipment Effectiveness (OEE)); Collecting and analysing process data, Handling variation, Statistical Process Control Charts, Natural Process Run Charts; Tools for continuous improvement (Flow charts, Cause Effect diagrams, Pareto diagrams, Check Sheets and Histograms etc).
Design and Control of safety in food manufacture and distribution	HACCP, GMP, PRPs – validation and verification protocols, Identification and Mitigation of biological, chemical and physical hazards, Packaging safety and integrity design, Mitigating packaging abuse.
Design and control of hygiene in food manufacture	Engineering factors influencing hygiene (such as process design, plant layout, containment requirements, process operation and control); Hygienic equipment design, fabrication and materials of construction.
Supply chain and food distribution	Sensors for environment monitoring and control, Data capture and analysis, Logistics and informatics relating to various food sectors (meat and poultry, dairy, fruit and vegetable and other sectors); Improving energy consumption, and lowering food waste and carbon foot print across the chain.
Economic Viability Analysis, Project Management and Legislative Framework	Accounting and Finance: Principles of accounting, Financial statements (Balance sheets, Income statements etc); Capital Costs and estimation methods; Operating and manufacturing costs; Project Revenues; Returns on investment or Profitability: Quantitative methods including Net Present Value and Discounted Cash flows, Sensitivity and Uncertainty analyses; Factors influencing profitability: Time Value of Money, Inflation related adjustments, Depreciation analysis, Cumulative Cash flows etc.; Project Management: Guidelines for Network Construction, Critical Path Method (CPM), Gantt Chart/Time Chart, PERT (Project Evaluation and Review Technique) Value Analysis and Value Engineering, Food related legislation.

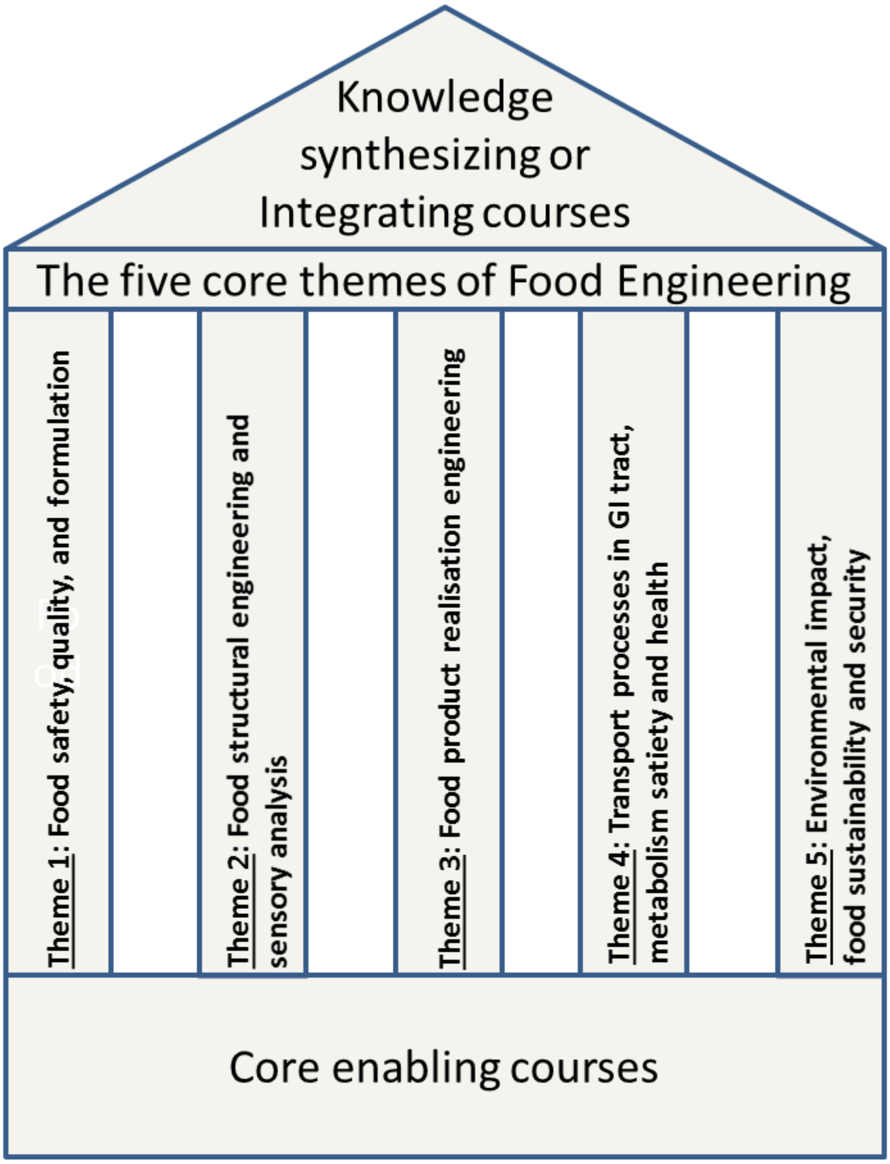

Figure 1: The *Food Engineering Edifice* consisting of five themes, each theme being illustrated through courses in Tables 2 and 3. It is critical to note that the above edifice only covers core subject-knowledge competency for food engineers; not the core professional competencies *per se* for engineers which are regulated in most countries. For instance, within UK, professional competence includes aspects such as: Responsibility, Management or Leadership, Communication and Inter-personal skills, and Professional commitment (http://www.engc.org.uk/ukspec.aspx).