Work In Progress: Design of a PBL-Centred Masters Programme in Nanoscale Manufacturing

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Summary

UCL East, the new campus of the University College London in East London will be opened in 2023. This is the single biggest expansion of the University since its foundation in 1826. With the aim to integrate research and education, theory, and practice – with cross-disciplinarity, innovation and public engagement, a need has emerged to build transformative programmes that will accommodate these objectives. This paper outlines the development of a Master's-level (MSc) programme in Future Manufacturing and Nanoscale Engineering. The programme is highly experiential; with a focus on both "learning by doing", and significant laboratory components (physical or computational) in all modules. A systematic process of programme design showed the need for a PBL-centred teaching and learning. The curriculum structure was designed to incorporate a "hub" of hands-on, open-ended activities in the form of manufacturing challenges. This practice may prove useful for the development of similar technical programmes, where the incorporation of PBL activities may be challenging due to the availability of specialist technology.

Keywords: Curriculum Design, Problem-Based Learning, Engineering Education, Active Learning, Skills Development

Type of contribution: Best practice extended abstract

1 Context: Programme Rationale and Development Framework

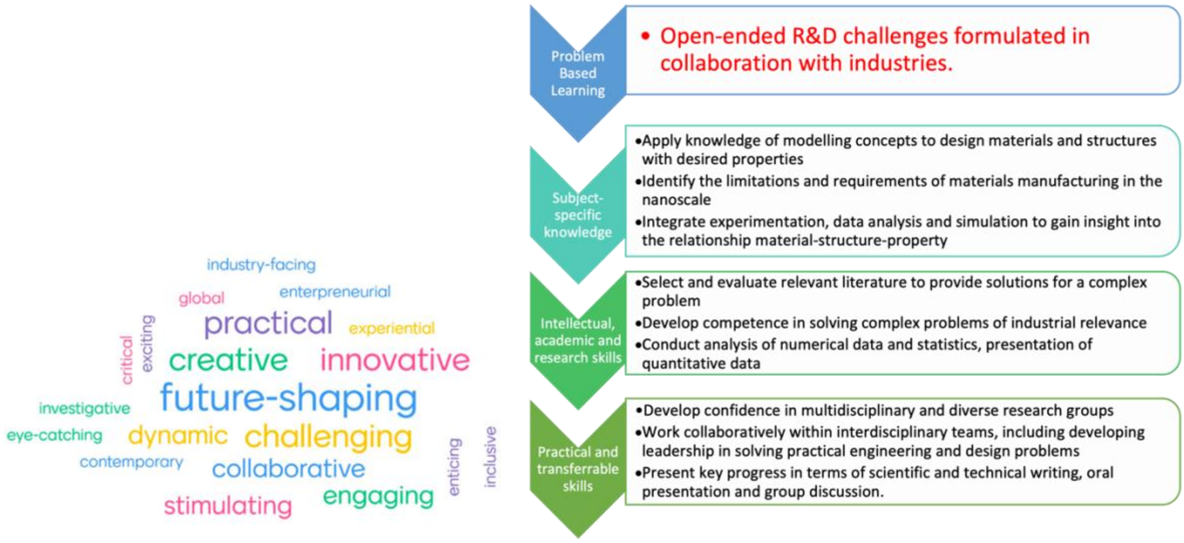
From modern diagnostics, construction materials to alternative energy solutions – a sustainable future relies on engineering strategies that can provide transformative solutions with ever-expanding applications. The field of nanoscale engineering fits many of these traits, and here we describe the development of a Master's-level teaching programme in Future Manufacturing and Nanoscale Engineering. The programme will be housed in a new, collaborative research laboratory formed by the departments of Chemical, Biochemical and Mechanical Engineering, and Chemistry. This MSc programme aims to engage students in the design, characterisation, and applications of nanomaterials, and their manufacturing techniques, to enable them to be leaders in this growing field. Ultimately, the students will be able to design manufacturing methods, critically analyse structure-properties relationships, make informed decisions about material limitations, and assess the environmental impact of design choices. The programme is unique in that it is implicitly more applied than other degrees in the field of nanoscale manufacturing.

The programme development process consisted of the following stages: 1) Conceptualisation, 2) Definition of programme-level learning outcomes, 3) Curriculum design, 4) Evaluation by external stakeholders, and revision. In this paper, we describe the methodology and outcomes of each of these stages, describing the rationale behind the choice for a problem-based learning (PBL)-centred curriculum. We expand on the design of these activities, their role within the curriculum and feedback received by independent reviewers.

2 Design of a PBL-Centred Curriculum

2.1 Programme Attributes and Learning Outcomes

The ideation of the programme started with a collection of 50-word summaries in a focus group of the development team. Subsequently, surveys of the current state of the art in education of this field were discussed, and a “wish-list” of the vision of the programme was generated as shown in Figure 1a. The above elements were used to generate programme-level learning outcomes in three main categories (Figure 1b; green). Here, “Subject-specific outcomes” relate to the application of a comprehensive knowledge of mathematics, statistics, natural science, and engineering principles to the solution of industry-relevant problems pertaining to advanced manufacturing and nanoscale engineering. “Intellectual, Academic and Research Skills”, focus on the interpretation of relevant literature to provide solutions to these problems. “Practical and transferable skills”, focus on providing confidence in working within a diverse research group through an emphasis on individual and team work, which is increasingly important in the execution of contemporary research projects.



(a) (b)

Figure 1: Programme vision attributes (a), and integration of learning outcomes (b)

The emphasis on demonstratable practical skills, and capability to respond competently to future challenges in this rapidly developing field made it clear that a comprehensive PBL methodology had to be developed. The role of PBL in Engineering Education has proven its effectiveness, especially in fostering competence in technical and durable skills (Aldert Kamp, 2020; Andersen et al., 2019; Andersen & Rösiö, 2021; ElMaraghy et al., 2021; Jamaludin et al., 2012; Kuppuswamy & Mhakure, 2020; Ríos et al., 2010). The inspiration for the incorporation of a “spine” of PBL activities that span the curriculum came from a successful application of this model within the Integrated Engineering Programme in our Faculty (Hailes et al., 2021; Mitchell et al., 2021). The main benefits of this model within the undergraduate curriculum have been to aid the development of design and professional skills. In our Master’s-level programme, the model’s intended primary functions are: 1) to integrate the distinct learning topics taught in the programme, and 2) to provide a venue for practical application and independent investigation of the taught topics within a design-build-test framework.

2.2 Integration of PBL Activities: Manufacturing Challenges

The programme structure is shown in Figure 2. It is taught in 3 Terms spanning 12 months, and consists of 6 taught modules. The Group Manufacturing Challenges contains a series of four 5-week challenges based on contents taught in modules 1-5. Examples of these challenges are: 1) Design and manufacturing of a nanoscale flexoelectric energy harvesting material, 2) Design/manufacture/test a microlattice material with high sttiffness/weight, 3) Design of a new alloy for additive manufacturing, 4) Design, fabricate and analyse high-precision components produced by additive and subtractive manufacturing techniques.

This module acts as the hub that integrates the rest of the modules and equips the students with an overall comprehensive knowledge and hands-on skills of the emerging manufacturing technologies. As Graff et al. states, these challenges would not only focus on evaluating the students' depth and breadth of learning but also on their ability to "fill in the subject area gaps" in advanced manufacturing (Graff & Kolmos, 2003). The challenges are open-ended complex problems with multiple solutions; thus, the learning is directly driven by problem-solving. In some challenges (e.g. example of Section 2.3), the manufacturing challenge precedes the content of the taught module, thus providing a valuable opportunity to learn through PBL principles.

A second advantage of this design is the opportunity to provide hands-on practical experience with characterising, manufacturing and testing of materials at micro/nano scales. For this purpose, the teaching laboratory has been equipped with 5-axis CNC precision machines, fibre-composite 3D printers, µCMM, SEM & AFM (material charecterization), profilometer (surface analysis), and metallographic preparation equipment. Various computational tools will be used, such as Thermocalc (materials development), CES Edupack (material selection, manufacturing process selection, sustainability analysis), Abaqus (FEA), and Fusion360 (CAD). This experience will thus: 1) enable students to apply a sophisticated knowledge base to solve real-world problems, and 2) provide evidence of practical skills which ill be useful for employment.

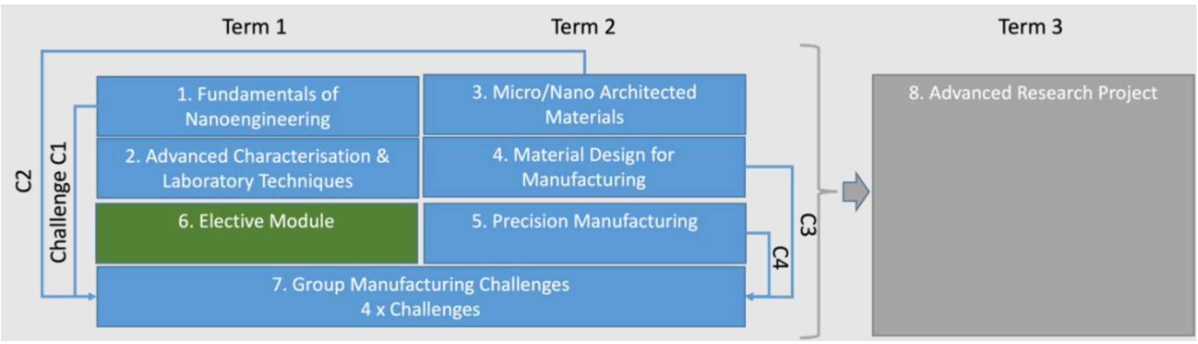


Figure 2: Structure of the Programme

2.3 Implementation: Manufacturing Challenge on Structurally Efficient Microlattices

Here we describe the structure of one of the manufacturing challenges. The students are expected to design microlattice materials with the objectives of: 1) exploring the material property space, and 2) designing materials with high strength/weight ratio. Microlattices are highly porous and cellular structures which are composed of periodic network of beams. Their stiffness and strength can be tuned through geometric design choices, and material selection, setting a loosely-defined design space with a specific objective.

Students will be asked to work in groups of 3-4 to design a sample of microlattice material with dimensions of 50 × 50 × 10 mm. They will be guided through the following workflow. First, use ASTM standards to determine the number of cells necessary to mimic an infinite lattice, using three different unit cells: hexagonal, gyroid and triangular. Second, for each type of unit cell, analytical models and Finite Element Analysis (FEA) modelling to determine constitutive properties are introduced. Third, manufacturing of prototypes in micro- and nano-scale with several additive manufacturing techniques is realised, and fourth, characterisation and mechanical testing is performed. The overall structure is shown in Figure 3.

The students work with their group members most of the time, with support and guidance provided from a series of lectures, example classes, workshop demonstrations and drop-in sessions, as below:

- Lectures; including introductory lecture to present the project brief and lectures by industrial guests to give students a vision of its impact in real-world scenarios,
- Example classes; to demonstrate how to use analytical models to obtain an initial design,
- Workshop demonstrations; including virtual lab to demonstration FEA for structural analysis and 3D printing lab for prototype manufacturing,
- Drop-in sessions; daily sessions run by tutors to help students with their individual questions.

This structure will make sure students can learn the technical knowledge by problem-solving before taking the taught module – Micro/Nano Architected Materials. This two-step learning process can give students both hands-on experience and further enhanced learning by more systematically structured lectures.

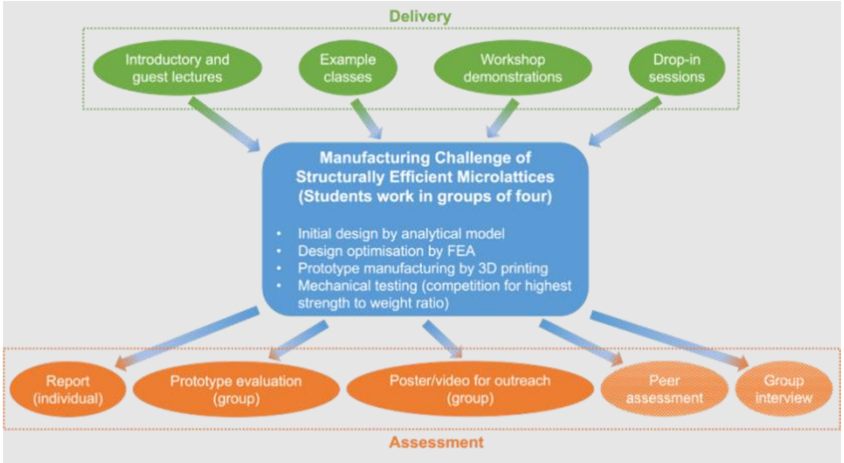


Figure 3: The overall structure of the manufacturing challenge

3 Evaluation of Effectiveness

The programme was evaluated by four groups of stakeholders: 1) an industrial advisory board, 2) an independent external scrutineer, 3) focus group of students external to the department, and 4) alumni of the department. Below, we summarise the main points of the feedback received.

The industrial advisory board included representatives from a range of industries, including Marine Engineering, Biomedical Engineering, Aerospace, and Manufacturing of Composite Materials. The audience included directors, CEOs, and CTOs of these companies. Their feedback focused on the involvement of industry on the Manufacturing Challenges.

The external scrutineer was a senior researcher with extensive specialist experience in nanoscale engineering, and in the design of similar programmes. The main improvement suggestions were in relation to the assessment of individual contributions in the group assessments in the Manufacturing Challenges and the Advanced Research Project modules, for which a detailed evaluation methodology was subsequently created and will be presented in our discussion in the conference.

The external student focus group highlighted the attractiveness of group work and hands-on training from the point of view of prospective students. The alumni praised the niche of the field and provided specific advice on marketing the programmme to prospective students. Of the 14 students interviewed, 6 stated that they would choose the programme as is, with the rest highlighting changes that would sway their decision towards their preferred careers, e.g. on finance, materials, design etc. The overall evaluation of the proposed curriculum was positive, with specific emphasis on the role and effectiveness of the PBL-centred design.

4 Current and Future Perspectives

In order to facilitate learning through PBL approach in this programme, adequate industrial/practical experience and up-to-date knowledge of industrial practice is required (Gani, 2019). The main challenge is to make nanoscale manufacturing accessible through a combination of bench-top experimentation and real-life industry-relevant experiential learning. This might be a common hurdle with many future-looking and highly specialist practical (engineering) programmes that are relatively niche. For example, manufacturing with nanoscale details and nano-inspection often require specialised equipment that students are not commonly exposed to, entering the programme with limited/none prior experimental skills to build upon. This partly has to do with an investment required to accommodate these tools and often, a special infrastructure.

While a wide access to the bench-top experimentation is one key element, the other concerns making the programme industry-relevant. To do so, we invested again in infrastructure – e.g., precision manufacturing lab - but we will also research closely with industrial partners through their supervision over a group project. In addition, we aim to equip our students with tools to effectively communicate their ideas to technical audiences and the public. All these PBL elements are designed to work synchronously so that graduating students will have the skills needed to work in any industry that uses design, manufacturing or materials.

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