2019-08-31

Composites Curriculum Development: tackling the skills gap in UK advanced composites

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http://hdl.handle.net/10026.1/15146

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COMPOSITES CURRICULUM DEVELOPMENT

Tackling the skills gap in UK advanced composites

August 2019

ABSTRACT

The aim of this project is to generate an industrially relevant and academically rigorous curriculum which could be deployed to tackle the significant skills gap in composites professionals, vital for delivering on the UK's National Composite Strategy and allowing the industry to grow to its full potential, forecast by the Composites Leadership Forum to grow by a factor of 5 by 2030. A Masters' level curriculum of short, industrially focused units has been specified and a small number of trial units developed. Engagement of academics in this novel collaborative curriculum development, utilising each institution's expertise, has been very good and feedback from industry and participants in pilot units has been positive. Consortium participants are investigating numerous options for developing this further and have begun to put plans in place for the next stage.

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ACKNOWLEDGEMENTS

National Composites Centre- key partner

Staff at University of Bristol and University of Plymouth

HEFCE/OfS for funding

Advanced Manufacturing Research Centre

University of Bath

University of Bolton

Cardiff University

Cranfield University

Imperial College London

National Physical Laboratory

University of Nottingham

Queen Mary University of London

University of Sheffield

University of Southampton

Ulster University

University of the West of England

Wrexham Glyndŵr University

Yeovil College University Centre

BMW

FAC Technology

Veale Wasbrough Vizards LLP

Wuhan University of Technology

Department for International Trade

EXECUTIVE SUMMARY

The UK advanced composites industry has the potential to grow very significantly over the next ten years due to new applications in aerospace, automotive, wind energy, construction and oil and gas. However, the current pool of trained and talented composites scientists and engineers is small and needs to be grown very rapidly if the opportunity is to be realised. The urgent need is to be able to retrain existing manufacturing professionals, alongside increasing the number of composites trained graduates coming out of the Universities. This project brings together Bristol and Plymouth universities, both leaders in composites education and training to provide innovative work-based curricula. Over the course of the project academic staff from numerous universities have worked together collaboratively, along with the National Composites Centre and National Physical Laboratory and through discussion with industrial partners; to quantify requirements, identify gaps, and produce a portfolio of flexible topic-based material. Material was trialled at the National Composites Centre and University of the West of England. In the future the curriculum is intended to be made available across a range of sectors and partners to be used for a variety of levels and audiences. Subject to successful bids for funding, we aim to start the process of delivering the volume of skilled workforce needed in composites, alongside demonstrating innovative approaches that could be applied to other emerging technology areas.

This curriculum offers an opportunity to tackle the skills crisis in composites. In order to achieve this, it is recommended that:

- A business case be constructed with a roadmap for success and options for funding through numerous short projects.
- One or more persons, funded as necessary, to take on responsibility for continuation of communication between participating institutions and to drive the next stage.
- Training needs analysis be carried out for the composites sector, including but not limited to the workshops discussed in the 'next steps section'.
- A vehicle for development and delivery of the curriculum be created, with members drawn from the current unofficial consortium and input from an industrial advisory board, with reference to the legal advice enclosed in this report.
- Knowledge capture interviews or similar exercises with experts of retirement age to be carried out and the resulting material used as teaching resources.
- The un-tested and second iteration units produced for this stage to be piloted, with feedback recorded and material modified appropriately.
- Further investigation into other courses which may hold useful lessons for this project, both in other countries and other subject areas, identified herein.

Contents

Introduction

Content of Report

This report is a compilation of work carried out during the HEFCE Catalyst funded Composites Curriculum Project. It is intended as a resource for continuation of this work in the next phase. The report describes the problem, the proposed solution and presents relevant data and options for the next stage.

The full dataset of anonymous feedback from the trial units and teaching material developed during this project are available in associated spreadsheet and presentation files.

Rationale

There is a significant skills gap in the UK composites industry. As the industry grows- and a generation of experts reach retirement- this is likely to increase, constraining the potential growth. The Composites Leadership Forum estimated that this industry has the potential to grow by £10Bn in 10 years, something which cannot be achieved without suitably skilled staff.

Provision of an industrially focused curriculum, at Masters' level, is intended to tackle this problem. Consisting of units which can be delivered according to industry need, engineers whose experience does not include composites; or new graduates without any composites background could attend those units most useful to their business. If possible, an option to add up points towards an academic qualification is considered worthwhile and options for this are discussed. Masters' level was chosen both because it is easier to develop at the highest level first and follow on with lower level material if needed than vice-versa, and because there are other training schemes under development at lower levels but the gap at Masters' level remains large.

Experts now reaching retirement present not only a significant loss of experienced persons, but also potentially loss of their accumulated knowledge and wisdom from varied and interesting careers. In addition to training the new generation of composites engineers, the proposed curriculum facilitates knowledge transfer directly from these experts to those attending the courses. At Masters' level, providing teaching material alone is not sufficient- the benefit which can be obtained from putting the experts in the same room as their students cannot be overstated. The curriculum should facilitate this, ideally starting with the consortium of experts who have contributed to this project.

The skills gap is not unique to the composites industry. The principles of the work presented herein could equally be applied to other areas, which stand to learn from the lessons of this project. In academia multi-institution collaboration on teaching is rare, compared to collaboration in research, but is necessary for this project as no single university holds the expertise necessary to deliver this course alone.

Under this project a curriculum has been specified, with proposed descriptions for each unit, which were reviewed by both academic and industrial experts. Pilot units were delivered to industrial audiences and modified based on their feedback. A record of current composites teaching at Masters' level in the UK is used to estimate the likely shortfall of staff for the industry without this course and is found to not meet the anticipated industrial demand. Options for future development, including intellectual property (IP), delivery of the course and appropriate awards or qualifications have been discussed and are presented herein.

Project Objectives

Scope of Project

This project seeks to define and carry out a limited pilot of a collaborative curriculum in composites manufacturing. The curriculum, intended as a method to tackle the skills gap in this area, will be at Masters level, with each academic institution contributing unit descriptions in their area of expertise.

The curriculum will be specified with reference to current available teaching in this area and to discussions with representatives of industrial manufacturers of composite parts.

Development of the full curriculum and final delivery structure is not in scope for this project.

Goals

A. Deliver a picture of the current composites teaching being carried out in the UK
B. Compare that picture with international benchmarks.
C. Generate a framework identifying the material that should be included within a composites curriculum.
D. Take a very limited number of the elements of that curriculum, develop delivery material and trial that material at the National Composites Centre.
E. Identify resource requirements to deliver the full set of teaching and associated supporting materials required to deliver the full curriculum.
F. Identify a sustainable structure by which ongoing delivery of the composites curriculum could be achieved and scaled to the industrial demand.

Milestones

1) *Curriculum mapping exercise*
2) *Demand and gap analyses*
3) *Contextual learning objects, materials and case studies*
4) *Pilot curriculum at NCC*

Demand From Industry

Staffing Needs

An initial estimate of staffing needs was carried out based on an estimate of the future composites market by the Composites Leadership Forum. Based on government figures, it is estimated that 5000 staff are needed for £1Billion turnover.

Of these, 5%-25% are at graduate level. The target of £12Billion turnover in 2030 would therefore require 3000-15000 graduates in work. For this, it is estimated that industry would need to recruit:

- 300-1500 graduates per year
- 60- 300 Masters graduates per year
- 30-150 Doctoral graduates per year

A spreadsheet with detailed calculations is included in the appendix and available on request.

This is an approximate figure, which we would like to refine with data from industry.

BMW have provided information on staffing levels needed for the i3 production, shown in the appendix. The i3 project alone needed to recruit 20-35 people with composites expertise at the first stage, of whom **15-25** should have masters' level or higher qualifications or equivalent experience.

At the second stage, they needed an additional 70+ people of whom **30** would need masters' level or higher qualifications or equivalent experience.

At the final stage, they needed an additional 40+ people of whom **20** would need masters' level or higher qualifications or equivalent experience.

Therefore, they required **70** people with masters' level or higher qualifications or equivalent expertise in addition to normal staff turnover, over 10 years. This is an average of 7 people per year plus normal turnover for a project of this size.

Checking the figures

Turnover was ~5% for engineers in the UK in 2017[1,2]. Assuming similar in Germany, 5% of 70 people is 3 or 4 people, so we estimate (erring on the high side) 11 masters' level or higher persons needed per year for this product, which achieved 16,052 cars or ~£500M for the first full year of sales in 2014[3].

Using that figure we estimate 22 masters' level or higher persons per £1bn per year which is in the range of 7.5-37.5 Masters or Doctoral level per £1Bn estimated above.

These would not necessarily all be new graduates- but anyone joining BMW to do this work leaves a vacancy elsewhere.

These figures do not include BMW's investment in its supply chain.

Automotive projects are generally quicker to market than aerospace. It would be useful to obtain figures from a range of sectors to fill this out further. Those two sectors, at very similar amounts, are the largest in the estimated 2030 market, according to the Composites Leadership Forum's 2016 UK Composites Strategy.

Demand For Training

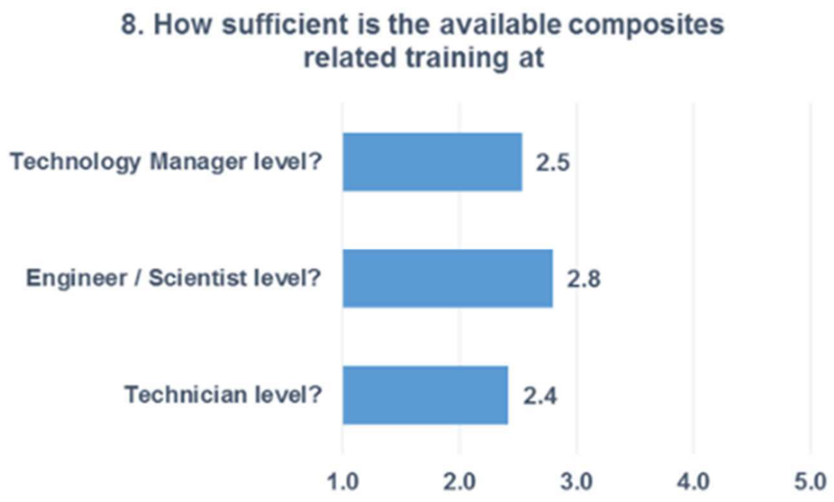
In order to provide the staff required, it will be necessary to train them. We expect this requirement to drive demand for this level 7 course and training at other levels. It has however been difficult to obtain a clear signal from industry regarding their view of training needs. Conversations to date suggest that industrialists source training when required- this will only be possible if the course exists at the time when it is needed.

NPL provided the below data from an upcoming report, which indicates that current training availability is considered inadequate.

[1] XpertHR Labour turnover rates
[2] https://www.e-days.co.uk/news/employee-turnover-rates-an-industry-comparison[online, 30/08/19]
[3] https://www.press.bmwgroup.com/global/article/detail/T0199942EN/bmw-group-sells-more-than-2-million-vehicles-in-2014[online, 30/08/19]

NPL data

*"In a cross-sector deep dive workshop that took place in BEIS (March 8, 2019) we asked **41** industrialists across Aerospace, Automotive, Defence, Marine, Infrastructure and Energy (Oil & Gas) to score the available composites related training between 1 (slightly) and 5 (very). The weighted average scores are shown below*



With L7 training targeting graduate engineers and above, it is fair to say that the workshop participants felt that the availability of training is below average (i.e., "3" mid-range) for these levels.

The focus of the workshop was on Regulations, Codes and Standards for polymer composites, however, there were a number of more general questions to capture industry's views.

We (NPL) will publish a report with all the workshop findings." (Provided by NPL)

Data from previous work

Pickard's 2018 thesis includes results of Knowledge Transfer Studies carried out with a variety of organisations in the composites manufacturing sector. Note that these organisations may not be considered a representative sample of the industry as a whole.

- The results show a lack of knowledge transfer between academic groups and almost all participating companies.
- Across all participating organisations, ~60% of participants felt they need to increase their knowledge in order to do their job.
- Current taught courses were considered useful by less than half of participants in large companies and SMEs, but over 60% of participants in academia and a research institution.
- Formal training courses were considered the most useful of a variety of options for knowledge transfer over all organisations.
- Results indicated a preference for interpersonal knowledge transfer.
- Web search was also a popular choice when searching for information.
- Very few participants (<30% in all organisations, <10% in larger companies) agreed that their organisation's current knowledge management practices work well. This includes training.

Composites Teaching in the UK

A mapping exercise was carried out to identify current (2018/19 academic year) composites courses at level 6 and 7 (Masters). Full details can be seen in the appendix.

- 91 courses at level 6 and above are offered by 31 UK institutions
- 71% of courses identified have compulsory composites modules
- Over half (54%) of courses identified are at MSc and MEng level
- The second most popular occurrence is short courses, which account for 22% of all courses identified.

Student numbers can be used to estimate the possible number of trained people who might be added to the workforce by these courses. It should be noted that for the short courses, an expert estimated that only 5% of students are UK based. While some international students join the UK workforce following their courses, many will instead find jobs elsewhere in the world.

It has not been possible to obtain figures for student numbers on all composites specific courses, but the Higher Education Statistics Agency (HESA) have student numbers by category for previous academic years.

In 2017/18, 68% of all students at UK HE institutions on Engineering and Technology courses were domiciled in the UK. For postgraduate courses in Engineering and Technology, the figure is 42% in both research and taught courses, for undergraduate courses it is 76%[4].

In 2016/17, 87% of UK domiciled students leaving a postgraduate course joined the workforce, as did 73% of those leaving an undergraduate course[5].

Based on these numbers we can reasonably estimate that for MEng courses (undergraduate), 55% of students are both UK domiciled and join the workforce, and for postgraduate courses 37% of students are both UK domiciled and join the workforce.

Over the 31 identified universities, in 2017/18 there were 59185 persons on undergraduate Engineering and Technology Courses (across 4 years) and 12915 persons on taught postgraduate Engineering and Technology Courses. Approximately 30% of the latter are part time, expected to be on 2 year courses.

Based on the numbers above, we estimate that if they all pass, approximately 4000 taught postgraduates and 8000 undergraduates will join the UK workforce from Engineering/Technology courses from the 31 universities each year. The majority of these will not study composites, and many of the undergraduates will take a BEng rather than an MEng.

[4] https://www.hesa.ac.uk/data-and-analysis/students/what-study [online, 30/08/19]
[5] https://www.hesa.ac.uk/data-and-analysis/publications/destinations-2016-17/introduction[online, 30/08/19]

Using the earlier figure of 22 new Master's level composite engineers per £1billion turnover and £12billion turnover in 2030, **we would need 264 persons per year, approximately 2.2% of Engineering/Technology graduates who join the UK workforce from the 31 universities.**

At the University of Plymouth, there is 1 person in the final year of an MEng with composites content in the 2018/19 academic year. In the year below, 5 of a total 45 persons studying an undergraduate course with composites content are registered for an MEng. Over all year groups there are 96 students on these courses in total, with 8 registered for the MEng. (data from Plymouth, pers.comm.)

If the 1350 undergraduates enrolled in Plymouth's engineering and technology courses in 2017/18 is typical, approximately 7% are studying a course with composites content and, averaged over the 4 years, **0.6% are expected to graduate with an MEng with composites content**.

According to the HESA 2017-18 data, 1840 undergraduates were enrolled on an Engineering/Technology course at the University of Bristol. In the 2018/19 academic year, the optional 4th year unit Composites Design and Manufacture was studied by 50 undergraduates. (data from University of Bristol, pers.comm.) Assuming ¼ of 1840 graduate each year, approximately **11% are expected to graduate with an MEng including the Composites Design and Manufacture unit.**

The HESA data states that 1735 taught postgraduates were enrolled at Cranfield University in 2017-18. In 2018-19, Cranfield University have approximately 90 students taking an M-level unit in composites, of whom approximately 50 are carrying out composites related projects for their thesis. (data from Cranfield, pers.comm.) If 1735 is typical, approximately **5% of Cranfield taught postgraduates are taking an M-level unit in Composites** and approximately 3% of Cranfield taught postgraduates show sufficient interest in composites to focus on this for their thesis.

As universities may differ significantly, it is not clear how widely applicable these numbers are. Using the Plymouth and Bristol figures as upper and lower bounds for undergraduates, and the Cranfield figure for postgraduates, these numbers suggest that approximately 48-880 MEng and 200 taught postgraduates with at least a single M-level module of Composites training join the UK workforce each year.

At the lower bound, this would not meet demand even if all these people chose to pursue a career in Composites Engineering.

Even at the upper bound, this would only meet demand if approximately **1/4 of graduates with at least 1 M-level unit of Composites** education chose to pursue a career in Composites Manufacturing.

Over the period 2012/13 to 2016/17, approximately 30% of Engineering/Technology graduates from undergraduate degrees joined the Manufacturing sector as a whole. 59% are recorded as working in "Professional" jobs. A Composites Manufacturing Engineer would fit both of these categories. It is highly unlikely that all of these people are working with Composites[6].

Finally, it should be noted that a single module at M-level can only cover a limited amount of information, delivering new Composites Engineers who will still need training in the areas most useful to their jobs.

[6] https://www.hesa.ac.uk/news/28-06-2018/sfr250-higher-education-leaver-statistics[online, 30/08/19]

International Benchmarking

Master's level courses in composites or with a clear composites component from a range of countries are summarised here for comparison to the proposed curriculum. A spreadsheet with full details is included as an appendix, with links to each course. It should be noted that the value of 1 credit is not the same in each country, so the total credits should be referred to when assessing how much of the course is composites related. For European countries, 1 European Credit Transfer System (ECTS) credit is considered approximately equivalent to 2 UK credits or 25-30 hours of study.

These were identified using the findamasters.com website and the resources complied by the University of Plymouth. It should be noted that this is not an exhaustive list, but represents that which is readily accessible to (mostly) English speaking internet users.

This includes 4 courses in France, 3 linked courses at a USA university, 2 in each of Belgium, Germany and Sweden, 1 in each of Australia, Canada, Denmark, Saudi Arabia and Turkey. In addition, one course is collaboratively taught across five universities in four countries (Belgium, Finland, France and Germany).

Of these 19 courses, 8 include compulsory material related to composites and 12 have either compulsory or optional content including at least some composites manufacturing content. The majority are full time, campus based courses, but the USA options are available entirely online. The Saudi Arabian course has a part time option. One of the German courses is designed to be carried out by employed people and taught in blocks, while one of the French courses includes an option to carry out part of the work as paid employment in industry. In addition to these two, seven others offer optional internships.

Collaborative course

The MSc in Advanced Materials for Innovation and Sustainability (Chemistry)[7] is offered by five universities in collaboration: University of Liège, Belgium; Aalto University, Finland; University of Bordeaux, France; Grenoble INP, France; T.U. Darmstadt, Germany. The two years must each be taken at different universities, with the second year being a specialisation. The Composites specialisation is taught at the University of Bordeaux. The degree is jointly awarded by the two universities chosen by each student. The options are limited by the student's preference for the second year specialisation- for example, to attend the second year at the University of Bordeaux, the students must study for their first year at either Grenoble INP, Aalto University or TU Darmstadt. The Master's thesis is jointly supervised by the 'home' and 'host' institutions.

This course also has industrial partners: ArcelorMittal, Luxembourg; Arkema, France; CEA, France; Fraunhofer, Germany; IMEC, Belgium. Students have the option in year 1 to undertake an internship, attend a summer camp working on industry case studies or work on a business model project. In year 2 students can carry out practical work on industrial projects or a business model project.

[7] https://www.u-bordeaux.com/Education/Study-offer/Masters-in-English/Chemistry/Advanced-Materials-for-Innovation-and-Sustainability-AMIS [online, 30/08/19]

Courses with Industrial Content

A majority of the courses offer an optional internship in industry, which may be used as a research project for the Master's thesis, and some include industrial case studies in the university based programme.

The course Éco-conception des Polymères et Composites (Eco-design of Polymers and Composites)[8] at the Université Bretagne Sud, France, has an option with more industrial content. The second year of the MSc can be spent based mostly in industry. The student spends the first semester alternating between the university and industry, with two weeks at each, and the second semester based entirely in industry. This is a paid job, which may lead to employment after the course concludes, and the work is used towards the student's project. This option is open to students under the age of 26 and employees or jobseekers over that age who meet certain conditions.

The Textile Engineering[9] course at RWTH Aachen is based at the Institute for Textile Technology (ITA) and has a more industrial focus than most. The course has two pathways, 'research' and 'coursework', with the latter including topics such as factory planning and production metrology. The students have access to specialised equipment at the ITA. Their research projects are either publicly funded or R&D for industry.

Professional Development Masters

The Verbundwerkstoffe (Composites) MSc[10] at PFH Stade Hansecampus, Germany, is intended for persons employed in industry, to carry out a Master's degree through professional development. In this respect it is planned similarly to our proposed composites curriculum. PFH is a private university.

The students study on campus at the university for blocks of 7-17 day courses, plus some weekend courses. Those who are based at the noted 'partner institutions' of Airbus, DLR and Fraunhofer, located near the campus, may find this convenient, but access does not appear to be restricted to employees of these organisations. The part time qualification requires 60 ECTS (~120 UK credits), though an option for a full time course of 90 ECTS (~180 UK credits) is also mentioned- this may be the English variant as it appears to involve more study time. Whether these result in different final qualifications is not clear. Students must carry out their taught units over 2 semesters only, with a third semester for the research project and thesis.

The course is taught in both English and German. The German variant can be studied with significantly fewer days away from work than the English, as more courses are taught at weekends. The German course comprises of one two week block, one single week block and five weekend courses (~31 days). The English course comprises of four 16 day blocks and a single weekend course (~66 days). A business module is taught via distance learning and 'blended learning' is also mentioned.

The course is delivered by "Professors with practical experience" and designed to be carried out while working full time. As such, this model is worth further investigation.

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[8] https://www.ecoconceptionpolymerescomposites.com/ [online, 30/08/19]
[9] https://www.academy.rwth-aachen.de/en/education-formats/msc-degree-programmes/textile-engineering [online, 30/08/19]
[10] https://www.pfh-university.com/studies/technology/composites-master.html [online, 30/08/19]

Chinese Universities

In addition to the above, Wuhan University of Technology have kindly supplied a list of 46 Chinese universities who teach composites specific courses, along with details of some of these courses (in Chinese). An expert who teaches Chinese to English translation at the University of Bristol has indicated an interest in working with these documents to produce a summary of which topics are taught where, particularly at a level equivalent to a UK MSc, MEng or MRes, and any industrially applicable teaching methods such as design/build/test projects or placements carried out in industry. Any future project may wish to consider this.

Proposed Composites Curriculum

The proposed curriculum, constructed by experts from a variety of UK institutions, is intended to be both industrially relevant and academically rigorous.

The intention is that the developed curriculum could be delivered by subject matter experts in response to industrial demand; organisations can choose the units most relevant to their business and utilise them as new recruit training or Continuous Professional Development. There may also be an option for individuals to build up credits towards an academic qualification.

Unit Portfolio

There are 5 core units which serve as an introduction to advanced composites. The 54 specialised units, directly relevant to design and manufacture of composite products in industry, are split into 9 blocks of 6, by topic. Each unit involves 2 days of teaching and an optional assignment, worth 2 credit points at Masters level.

An organisation can choose either a full course structure or individual units to fit their requirements.

List of units

Core (5 units)

- Introduction
- Composite Constituents
- Manufacturing of composite products
- Product design
- Properties of composites

Materials (6 units)

- Polymeric matrices
- Polymer melt viscosity and chemorheology, cure and degradation
- Fibres and moulding compounds
- Characterisation techniques
- Dry fabrics and prepregs
- Characteristics of fabric reinforcements- drape, conformability, permeability etc

Product Design A (6 units)

- The design cycle and requirements capture
- Costing in a design environment
- Drawing practices and lay-up rules
- Design for manufacture
- Acceptance criteria, rework, concessions- designing out defects
- Standards and Certification

Product Design B (6 units)

- Micromechanics
- Laminate design and analysis
- Stress analysis - classical
- Stress analysis – Finite Element Analysis
- Joints – bonded, bolted, 3D structures
- Damage tolerance

Manufacturing Processes A (6 units)

- Reinforcement manipulation and preforming
- Contact moulding: hand lamination and spray
- Prepreg processes: vacuum bag
- Prepreg and SMC processes/compression moulding
- Resin transfer moulding
- Resin infusion processes

Manufacturing Processes B (6 units)

- AFP and ATL
- Rapid prototyping and additive manufacture
- Filament winding and pultrusion
- Thermoplastic matrix processes
- Process automation
- Processes for Ceramic Matrix Composites and Metal Matrix Composites

Manufacturing Operations A (6 units)

- Production costing
- Process design
- Process modelling
- Process monitoring, Quality Assurance and Quality Control
- Process planning
- Tooling design and manufacture

Manufacturing Operations B (6 units)

- Joining and assembly
- Factory design and layout
- Lean, Six Sigma and similar methods

- Tolerancing, variability and defects
- Machining composites
- Surface finishing and painting

Performance A (6 units)

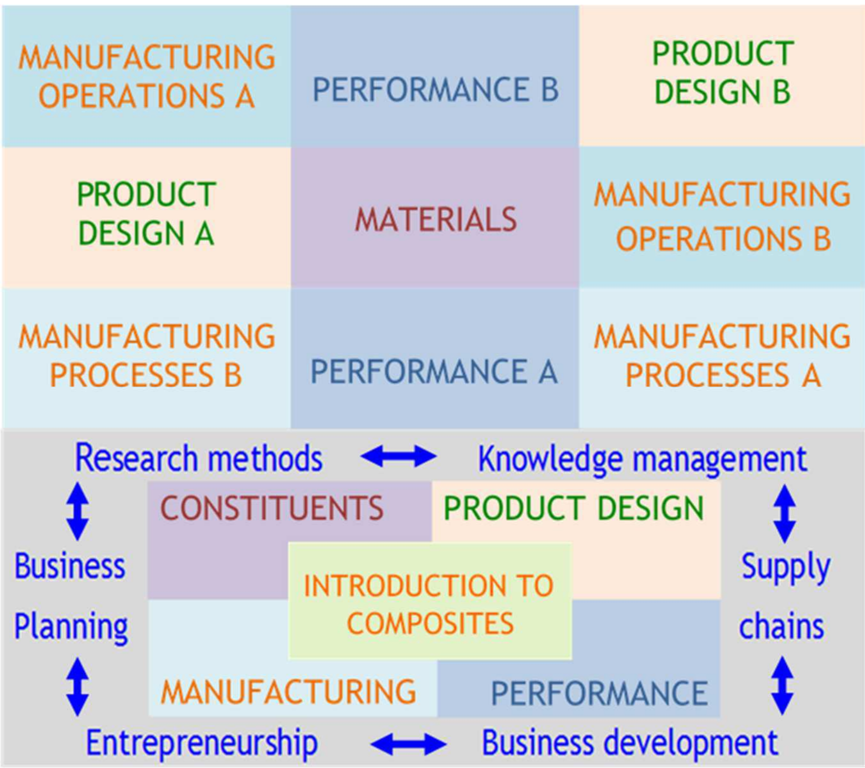
- Mechanical properties and testing - anisotropic elasticity
- Mechanical properties and testing - static strength, failure modes and failure criteria
- Mechanical properties and testing - dynamic and fatigue, crashworthiness
- Durability: weathering, moisture diffusion, osmosis and blistering and galvanic corrosion
- Non-structural properties - erosion, wear, electrical and thermal properties
- Fire and post-fire performance of composites

Performance B (6 units)

- NDE, condition monitoring, structural health monitoring and in-service inspection
- Multifunctional composites
- In service damage and repair
- Recycling and reuse
- Sustainable composites
- The broad perspective on composites.

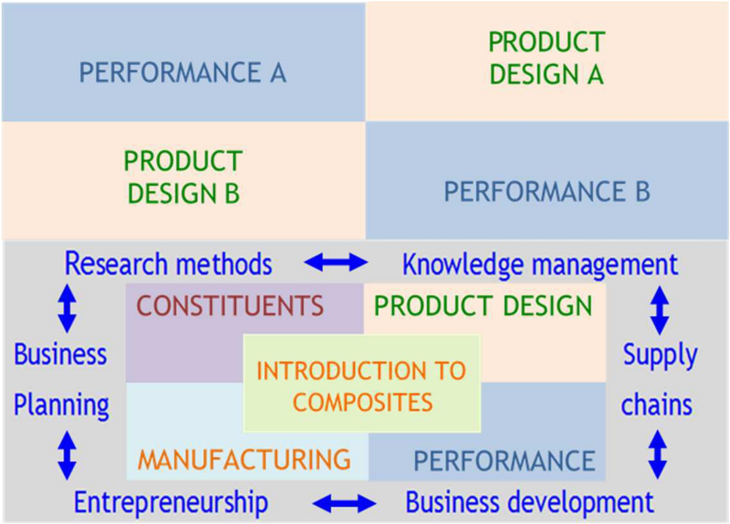
Schematic

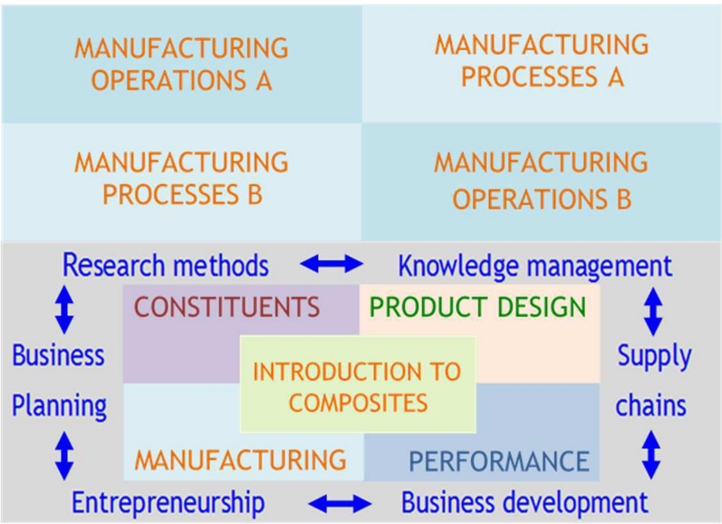
The course structure is shown in the diagram below.



Example Combinations

For organisations requiring a full course, this can be tailored by choice of blocks or units. Examples of a Product Design led combination (left) and a Manufacturing led combination (right) are shown below.





Reviews

The unit descriptions and overall curriculum were reviewed by both academic experts and, on behalf of industry, the National Composites Centre.

It was noted that learning outcomes should be checked for consistency and all should be at M-level. Some units may require prerequisites. This should not be a specific course, but necessary knowledge- for example, if the student needs to be familiar with differential equations this should be mentioned. It was not considered a problem if a small number of units require a mathematical background as no individual will need to complete all the units, but they should be kept broadly accessible where possible. It may be reasonable to provide some pre-course reading if students are likely to need reminding of mathematics that they have not seen since their school days.

Some unit descriptions were commented on in more detail by academic reviewers, to ensure all required content is covered.

Resources developed to date

Contextual learning objects

Case studies and other resources

A series of web elements have been prepared which can be loaded into webpages elsewhere using the iframe capability in HTML

- The **Composites Courses**[11] web element provides links to appropriate training and education for composites in the context of Schools, Apprenticeship, Colleges and Universities, and further links for careers, continuing professional development, professional accreditation and ultimately professional recognition.

- The new **Case Studies**[12] web element brings together links for over 100 individual webpages describing applications of composite materials, categorised under Aerospace, Architecture, building, civil and structural engineering, Automotive, Bridges and walkways, Chemical plant, Defence, Delivery solutions, Design, materials and miscellaneous, Furniture and fittings, Machinery, Manufacturing processes, Marine and watersports, Modelling, Renewable energy, Railways, Sports

- The new **Composites Resources**[13] web element provides links to Books/chapters (as free downloads), Best Practice Guides, Conference series archives, Coventive Explains series, JS' virtual books, Kindle books at <£10 and other on-line resources.

- The new **Videos**[14] web element provides links for a selection of videos which might help understanding of the respective concepts.

- Further, a pre-existing resource identifying **Review Papers**[15] relevant to composites design and manufacture has been continuously updated.

Images, Videos and Physical Objects

The University of Bristol have compiled a catalogue of images and videos which can be used in this curriculum. Many of the images are photographs of physical objects currently held at the University of Bristol which demonstrate important aspects of composites manufacturing.

Videos of lectures

The majority of lectures delivered as part of the third pilot- *Tolerancing, Variability and Defects* and *Production Costing*- were recorded, with permission from attendees. Clips from some of these lectures have been included in the second version of the slides, using the lecturer's anecdotes to illustrate points.

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11 https://www.fose1.plymouth.ac.uk/sme/composites/courses.php [online, 30/08/19]
12 https://www.fose1.plymouth.ac.uk/sme/composites/case_studies.php [online, 30/08/19]
13 https://www.fose1.plymouth.ac.uk/sme/composites/resources.php [online, 30/08/19]
14 https://www.fose1.plymouth.ac.uk/sme/mats347/videos.php [online, 30/08/19]
15 https://www.fose1.plymouth.ac.uk/sme/mats347/ReviewPapers.htm [online, 30/08/19]

Knowledge Capture Interview

A Knowledge Capture interview was carried out with Professor Kevin Potter, an expert who retired during the course of the project. Prompts based on questions from current and former IDC students- who carry out their research projects in industry were used as starting points, from which Professor Potter talked about his experiences, interesting anecdotes and his opinions regarding composites manufacturing. Following the principles of knowledge capture during exit interviews, Professor Potter was encouraged to talk through his thought process, use examples, compare different options and give a clear final message. It is recommended that the interview be transcribed, and split into short clips based on topic, which can be used in lectures or other teaching resources as with the videos above. It would also be worth producing a full length video of the interview, edited for pauses and the interviewer's questions, for those who are interested to watch.

These resources are available on request.

Example units

Draft versions of core unit material were developed for the first pilot. Approximately half of core unit 1 was then refined and re-developed for the second pilot. Two full example units were developed in full, save for the assignment, for the third pilot. All of these were carried out by Professor Kevin Potter at the University of Bristol.

In addition, Dr Nuri Ersoy of the University of the West of England and Dr Stefanos Giannis of the National Physical Laboratory each developed a single example unit.

The time required to develop each of the four full example units was recorded by each unit director. This is used to refine estimates of the resource requirements for developing the full curriculum. The four units each cover significantly different topics and types of teaching- for example, some require hands-on exercises while others use computer based exercises- and were developed in three different institutions, so taken together these are considered to provide a reasonable estimate of likely resource requirements for the whole curriculum.

List of example units

Unit 2-6 Standards and Certification

This was developed by Dr Stefanos Giannis and colleagues at the National Physical Laboratory.

Unit 6-1 Production Costing

This was developed by Professor Kevin Potter and Dr Carwyn Ward at the University of Bristol and was delivered to a trial class at the National Composites Centre. A second version of the slides and class exercise was created in response to feedback from the trial.

Unit 7-4 Tolerancing, Variability and Defects

This was developed by Professor Kevin Potter and Dr Michael Elkington (practical component) at the University of Bristol and was delivered to a trial class at the National Composites Centre. A second version of the slides was created in response to feedback from the trial.

Unit 8-1 Mechanical Properties and Testing – Anisotropic Elasticity

This was developed by Dr Nuri Ersoy at the University of the West of England.

Report on Trials

Three pilots were carried out using draft course material. Pilot 1 and Pilot 2 used material from the core units, while pilot 3 was a full-scale trial of two units from the main curriculum.

Pilot 1- NCC Composites Conversion Course

The NCC Composites Conversion Course is intended for persons experienced in working with other materials. Advanced composites require a very different approach to, say, metals, through the whole design, manufacture and test process.

The pilot for the NCC course was delivered in April 2018. This included material from initial drafts of the five core units of this Composites Curriculum. No formal feedback was gathered, but informal responses were very positive, supporting the decisions made regarding the content of the core units.

Pilot 2- UWE CPD Course

In February 2019, Professor Kevin Potter delivered a condensed version of approximately half the material in core unit 1, Introduction to Composites, as part of a Continuing Professional Development Course at the University of the West of England. *An Introduction to the History and Manufacture of Composite Materials* was a 1 day course. 3 hours of lectures were supplemented by handling physical samples of composite parts, test coupons and materials as well as a question and answer session.

The 10 attendees, including the UWE academic who arranged the course, completed an anonymous feedback questionnaire. Utilising a mixture of quantitative ratings and space for opinions to be expressed, this questionnaire was intended to identify both problem areas and those aspects which worked well. The questionnaire also included demographic questions regarding the number of years' experience the respondent has in science/engineering in general and composites in particular, and the nature of their job. No personal details were collected.

Only one attendee declared prior experience working with composites. In science/engineering in general experience ranged from a student with no industrial experience to 17 years. 8 of the attendees had 5 years or more of experience in science/engineering, of whom 3 declared over 12 years' experience.

The feedback was largely positive, with 8/10 rating their enjoyment of the course positively and 2 neutral. The majority (8/10) considered the course interesting and expected to refer back to their notes in future, despite the fact that few thought the topics relevant to their work.

Areas for improvement were also identified- most participants felt there was too much content for the time available and slides were considered overly verbose.

9/10 attendees thought the content made sense, the lecturer was easy to understand and considered the industrial examples included in the slides and handling composite parts beneficial. Half the students chose one of those two aspects as their favourite part of the course. No-one rated the course too easy, with the majority placing the level at 'perfect'. 4/10 considered it difficult, though none excessively so.

6/10 participants were interested in learning more about advanced composites, likewise 6/10 were interested in the concept of adding up points from such a course towards an academic qualification. However only 3/10 thought an optional assignment would be useful to consolidate the learning.

Pilot 3- 2 units at NCC

Two units from the main curriculum were delivered in full at the National Composites Centre in late March and early April of 2019. Each unit was taught by Professor Kevin Potter, with contributions from colleagues, over two days, following development of the material specifically for this purpose.

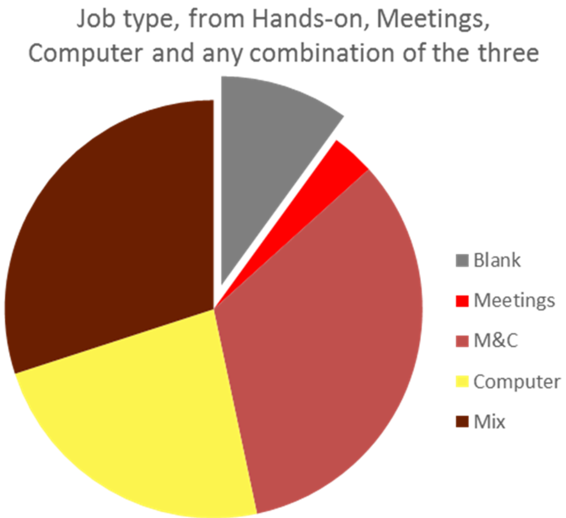
This final pilot served as the most realistic trial of this curriculum to date. Participants were staff members from NCC and manufacturers of advanced composite components in the aerospace industry. The only aspect not included was the optional assessment, as we are unable at this time to offer credit points towards an academic qualification.

As the units were delivered free of charge and were advertised only to NCC member companies at short notice, the level of interest and companies represented cannot be considered representative of the general case. The majority of participants were from larger companies. Participants were asked to fill out a feedback form similar to that used for Pilot 2.

Unit *7-4 Tolerancing, Variability and Defects*, from the *Manufacturing Operations B* block, was trialled in March 2019. All lectures and classroom exercises were delivered by Professor Kevin Potter and the practical session was led by Dr Michael Elkington. 14 of the 16 attendees filled out the questionnaire, all but one of whom currently work with advanced composites. Experience in composites ranged from none to 8 years, with the majority having 1-5 years' experience. All attendees had 2 or more years' experience in science/engineering in general, up to a maximum of 18 years, with most in an 8-12 year band.

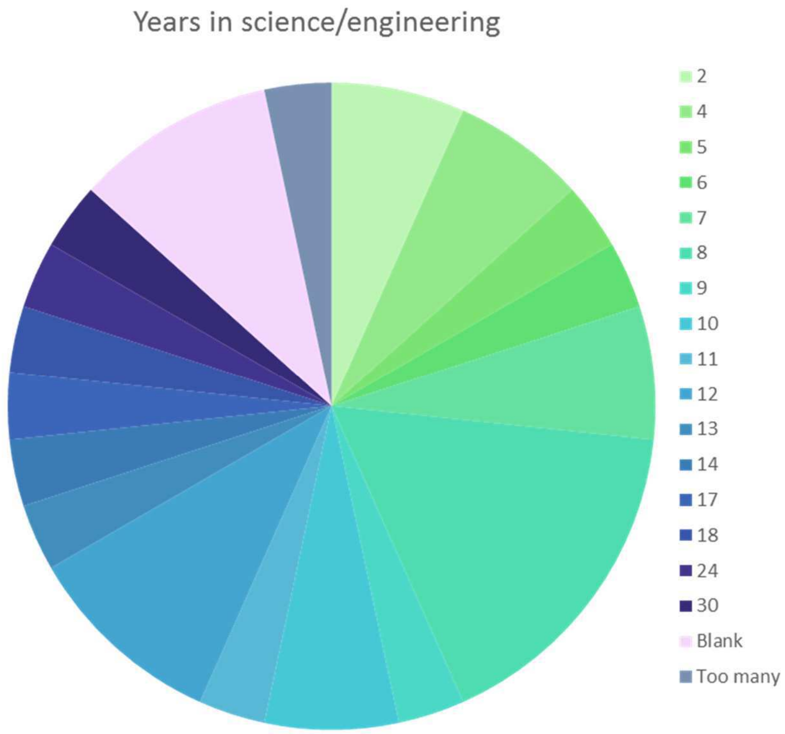
Unit *6-1 Production Costing*, from the *Manufacturing Operations A* block, was trialled in April 2019. The first day of lectures and classroom exercises was delivered by Professor Kevin Potter, the second day- including the 'Virtual Composites Company Spreadsheet' was delivered by Dr Carwyn Ward. 6 of the 8 attendees filled out the questionnaire. 4 declared that they currently work with advanced composites. Two people recorded over 15 years' experience with advanced composites and over 24 years in science/engineering in general.

Summary of Participant Feedback

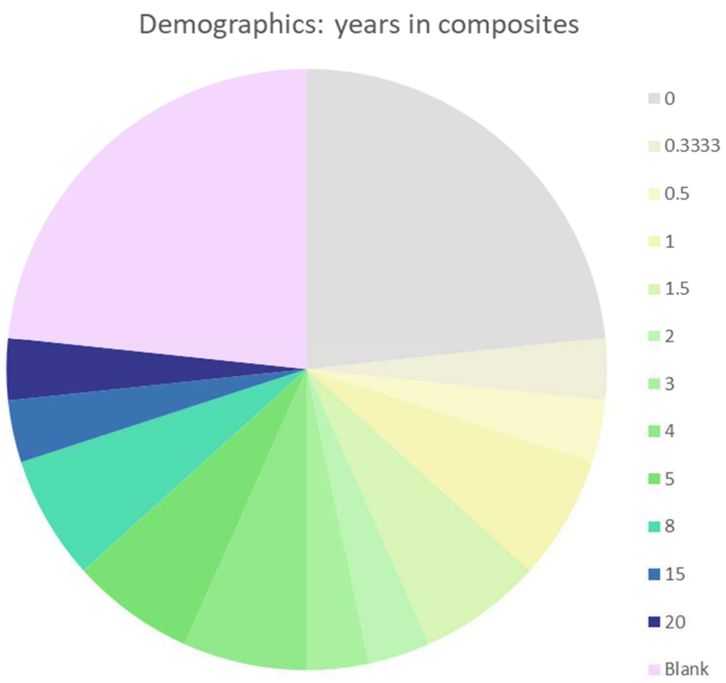


No participants worked exclusively hands-on, with most spending some time in computer based work.

Demographics

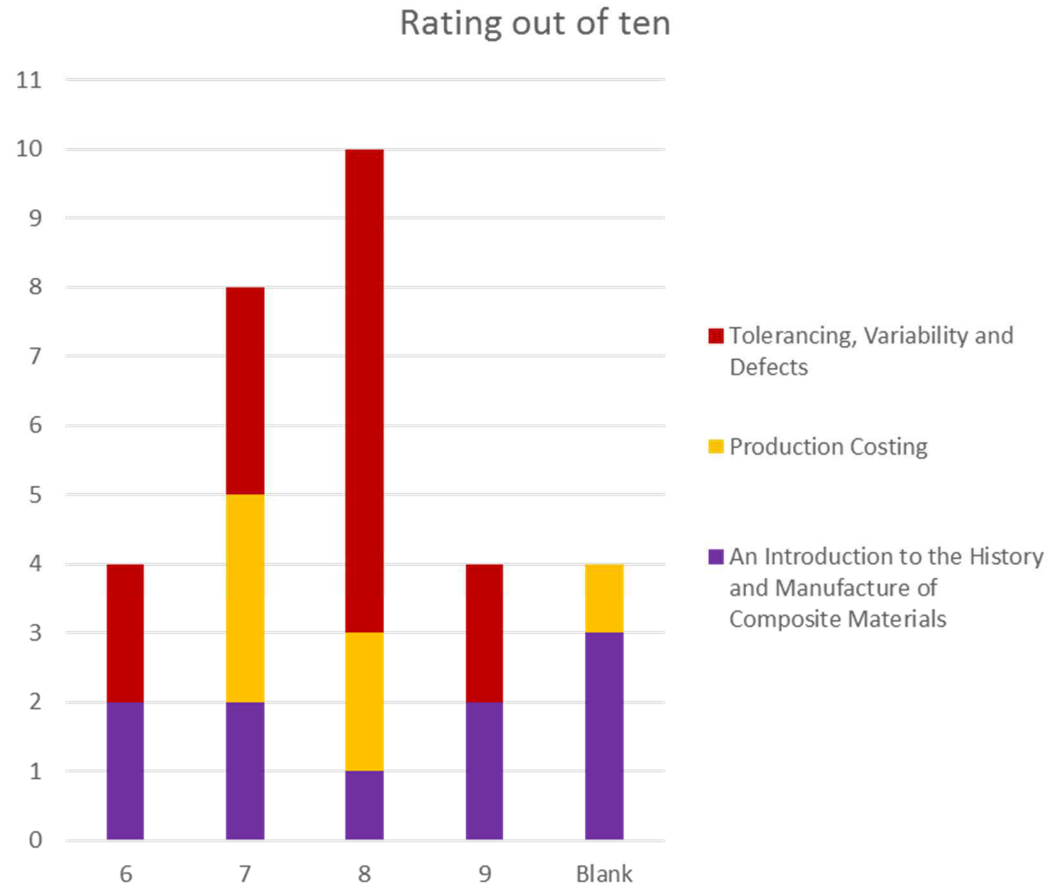


Over all three courses where data was collected, there was a large range of years' experience in science and engineering among participants.



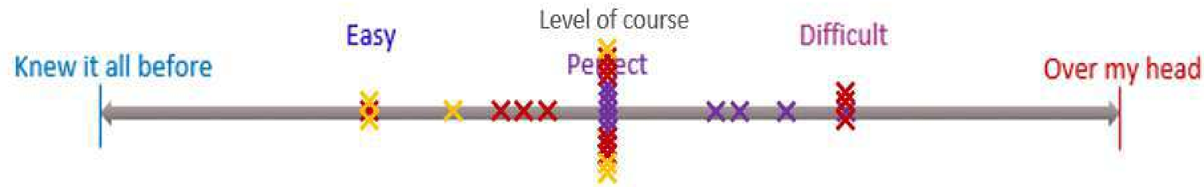
The majority of participants had relatively little experience with composites, none at all, or did not say.

Overall rating of the courses



No ratings of less than 6/10 were received. 4 participants did not answer this question. Of the total 30 questionnaires, no participants stated that they did not enjoy the course. 4 gave a neutral rating, 20 said ‘yes’ they enjoyed it (including all 6 from Production Costing) and 6 selected ‘amazing’.

Level of difficulty



Using the same colour scheme as above- the majority of participants rated the level of difficulty as ‘perfect’ by placing a mark on the above scale. None went outside the ‘easy-difficult’ range. None of the students on the introductory course considered it easy, and no-one found the production costing course difficult.

Key comments on content

The free text questions regarding students' favourite and least favourite parts of the courses, topics they would like to know more about and suggestions for improvement elicited a range of responses, which are all available in the spreadsheet. As the three courses are different these are difficult to compare, but some general points can be made:

- No negative responses to "Did you enjoy the course?"
- The practical exercises and industrial examples were popular
    - ***"The practical section of laying up prepreg was very useful. This made it clear how difficult it is to avoid defects with some geometry"***
- There is demand for worked examples and case studies
    - ***"More group problem solving to discuss real life issues as these help the understanding of the presented material"*** ***"Can do with more examples!!"***
- We need to make the level of the course and any expected prior knowledge clearer
- There was demand to add material which fits in other units- when the full curriculum is available it will be possible to refer students to the relevant units.

Some more relevant quotes:

- ***"Make easier to understand slides, less text, more figures and graphic examples"***
    - This was a very popular point. The most common complaint was that the slides were too verbose. This is one of the main issues being tackled in creating version 2 of the Production Costing and Tolerancing, Variability and Defects teaching material.
- ***"It's easier to learn when you have time i.e. not working"***
    - The course is useful, but completing assignments might be difficult for students whose employers cannot afford to lose them. This is particularly relevant for students from SMEs, who are less likely to have other employees who can cover for the student.
- ***"Kevin's industrial expertise is invaluable. If the presenter just followed the slides it could be boring. Kevin's anecdotes & tips/gems are key to this"***
    - This quote, and other comments along these lines, demonstrate the value of having an expert carrying out the teaching- someone who can answer questions and come up with relevant examples from their working career. This suggests that a train-the-trainer model may not be appropriate for courses at this level.

Overview of participant opinions

Participants were asked to rate their level of agreement with a set of statements on a Likert scale, from -2 (disagree) to +2 (agree). The graphic overleaf shows those who indicated agreement, at +1 or +2, with the statements, coloured by their years of experience in science/engineering.


The course was interesting
The content made sense
The topics we covered are applicable to my work
The industrial examples were a valuable inclusion
The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)
I have more questions now than before attending the course
The lecturer was easy to understand
The slides are well laid out
I am likely to refer back to the handouts and/or my notes from today
I had sufficient opportunity to ask questions
There was too much content for the time available
I would like to learn more about advanced composites/other topics in composites manufacturing
My company would benefit from (more) training in advanced composites
An optional assignment would help to consolidate what I have learned
I would be interested in adding up points from courses like this towards an academic qualification
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Statement	-2	-1	0	1	2	Blank
The course was interesting			2	12	16	
The content made sense			2	17	11	
The topics we covered are applicable to my work	1	5	5	9	10	
The industrial examples were a valuable inclusion			1	8	21	
The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)			6	3	20	1
I have more questions now than before attending the course	3	5	12	4	6	
The lecturer was easy to understand			2	10	18	
The slides are well laid out	1	2	5	13	9	
I am likely to refer back to the handouts and/or my notes from today		2	3	12	13	
I had sufficient opportunity to ask questions	1		3	6	20	
There was too much content for the time available	3	11	4	7	5	
I would like to learn more about advanced composites/other topics in composites manufacturing	1	1	3	5	19	1
My company would benefit from (more) training in advanced composites	2	1	4	8	13	2
An optional assignment would help to consolidate what I have learned	2	3	7	13	4	1
I would be interested in adding up points from courses like this towards an academic qualification	1	2	6	10	10	1

The highlighted points indicate demand for an academic qualification from 2/3 of participants and show that over half of participants see an assignment as valuable for consolidation of learning.

All but one participant (who was neutral) agree that the industrial examples are useful, demonstrating that such examples should be included in all units. It should also be noted that there were no negative responses to the statements 'The course was interesting', 'The content made sense' and 'The lecturer was easy to understand'.

Most participants thought they would refer back to their notes. Providing good quality material is important here, particularly if the text on the slides is reduced, as students may not have time to write sufficient notes themselves. For this reason, the lecture slides being modified for ease of viewing will be accompanied with a written document based on the original text, so that the detail is not lost.

Most participants expressed an interest in learning more and felt that their companies would benefit from training in advanced composites.

Delivery of Curriculum

Resource requirements for material development

Prior to the trial units, the following estimate was used:

At 30 minutes to create a slide, 30-40 slides per hour of lecturing, it takes approx. 125 person-hours for 7 hours of lecturing. This is 2.5 to 3 days of work for an hour's lecture.

The 125 person-hours is doubled to allow for class exercises, practical activities, assignments and other non-lecture items, giving approximately 250 person-hours per unit, or ~ 35 person-days to make a unit, assuming the person starts with no previously prepared material available.

This results in approximately 2000 person-days for the whole curriculum, or ~10 person-years of work time.

Estimates from other sources vary, with NPL suggesting 25 hours' preparation for 1 hour in the classroom, so 300 person-hours per unit, ~43 person-days. By contrast, UWE estimated that a single expert could prepare a unit of material in 12 days, broken into 6 days for slides, practical and a mini assessment and 6 days for creating illustrations for the slides. It is possible that this expert had material from elsewhere which could be used.

Results of example unit development

Tolerancing, Variability and Defects

Professor Kevin Potter reported that the Tolerancing, Variability and Defects unit took 60 hours of development, based on modifying existing materials rather than starting from nothing. The resulting slides were then modified, by more junior persons with composites knowledge, to produce a more visually attractive and easier to read set of slides plus a reference document containing all the additional text. This took 48 hours. In addition, Dr Michael Elkington developed the plan and guidance for the practical session. The total development time for this unit is estimated as 120 hours, and it should be noted that this did not start from nothing.

Production Costing

1 day (~half) of the Production Costing unit took Professor Potter 30 hours, with the second day developed by Dr Carwyn Ward. Again, this was based on modifying material which was already available. The slides were likewise modified following the trial unit and a worked example for the Virtual Composites Company spreadsheet was produced. For this unit the modification work took 86 hours. The total development time for this unit is estimated as 150 hours.

Mechanical Properties and Testing: Anisotropic Elasticity

Dr Nuri Ersoy delivered a set of slides and suggested assessment following the 12 days of work. At 6 hours per day this is 82 hours. There are significantly fewer slides than in the above two lecture packs, though it is likely that more time will be spent on laboratory sessions for this unit. This material would optimally have an accompanying text and/or recording of an expert delivering the material for later reference. Based on feedback from the pilots, inclusion of industrial examples would be beneficial.

The assessment refers to practical testing which would be carried out either by the students or a suitably trained demonstrator as part of the 2-day course. For this topic a practical component is vital. The assessment will involve interpretation of the results. The suggested assessment allows combination with other units (e.g. producing panels in one unit to cut into test coupons for another), which could help students to appreciate the bigger picture but may not always be practical- for example, not all students will take the same units and they may not always be geographically or chronologically convenient. The assessment can also be standalone.

Standards and Certification

NPL developed the Standards and Certification unit following a different model. Three experts developed the technical material, which was then passed to their internal training team for conversion into slides.

This unit includes three exercises, all of which involve planning trials based on the principles presented in the lessons. Practical testing and data analysis are included in some of the exercises. In principle, following the example of Mechanical Properties and Testing: Anisotropic Elasticity, these exercises could form the basis of an assessment. The exercises require use of relevant standards. The standards are not included in the material provided, due to IP restrictions, but students on this unit will reasonably require access to standards in order to learn how to read and apply them.

Summary

Unit	Institution	Time	Cost	Content
Tolerancing, Variability and Defects	Bristol (internal)	120 hours	£3252 (estimate)	245 slides, 6 handouts, practical session guide
Production Costing	Bristol (internal)	150 hours	£3974 (estimate)	255 slides, 7 handouts, worked example for calculation spreadsheet
Mechanical Properties and Testing: Anisotropic Elasticity	UWE	82 hours	£7678	135 slides + new diagrams, practical guide/assessment
Standards and Certification	NPL		£42250+VAT	309 slides, 3 exercise guides, calculation spreadsheet + instructions

The units developed by academics at the University of Bristol and University of the West of England all took significantly less time than the initial estimate, but in each of these cases the academic had access to material prepared for other courses to modify, reference or use as a starting point. The Virtual Composites Company spreadsheet used in Production Costing is an existing teaching aid.

The time taken for producing the initial teaching material is similar for three units, being ~60-70 hours for the two Bristol units and 82 hours for the UWE unit. As the UWE unit required production of new graphics and illustrations it is to be expected that this should take longer. The greater cost of the UWE unit is likely to be due to the difference between in-house work at Bristol and external work for hire from UWE. Bristol costs were estimated from the internal costs applied to the project.

The post-pilot modifications to the Bristol units added significantly to the time- though less to the cost as these were carried out by more junior staff. The slides are visually improved, making them easier to follow, and the addition of handouts for later reference by the students will be valuable. It should be noted that the handouts produced for Production Costing were formatted as standalone documents and edited/rewritten for readability, whereas those produced for Tolerancing, Variability and Defects were largely copied verbatim from the original slide set. Production Costing also included addition of a worked example, something demanded in student feedback.

It should be expected that any course will need some modification following pilot delivery, and addition of handouts or other supplementary material would be valuable for all units.

The Standards and Certification unit was notably more expensive, but developed following a very different method. The total time taken is not yet known, but given the number of people working on the project and the likelihood of not having previously written material this can be expected to have taken significantly more person-hours.

It should be noted that quantity does not equal quality- for example a course with more lab work is expected to require fewer lecture slides.

Future development will require a set of 'known good' teaching material to act as a model, and/or more detailed guidelines. The very different outputs of the example units demonstrate this need. As a first task, any follow on project should decide on what a 'good' unit requires.

Models for delivery

Feedback from the pilot units demonstrates the value of learning from an expert. It is proposed that the units be delivered in response to demand, with experts travelling to a location convenient for the students. Options for the location depend on the unit- Production Costing could reasonably be taught anywhere with a suitable meeting room, whereas Fire and Post-fire Performance can realistically only be taught at the University of Bolton due to their unique facilities. Most units will be accessible at a range of sites, with the National Composites Centre in the south, and Advanced Manufacturing Research Centre in the North, being good locations for accessing equipment in many cases.

It is of course possible to create videos for off-site teaching, but these are no substitute for hands-on experience and engagement with experts face-to-face. For the students to gain as much as possible from these units, it is recommended that the practical aspects should be considered vital. Both the feedback from the trial units and a wealth of literature on the value of learning by doing (*I can add references here if necessary*) attest to this.

A train-the-trainer model was discussed, but it was considered inappropriate for material at this level, and unlikely to deliver comparable results to teaching carried out by an expert. A network of experts, willing to travel, is in itself beneficial to improving knowledge transfer in composites manufacturing, particularly between academia and industry. Results presented in Pickard's 2018 thesis demonstrate that for the companies who took part in the presented knowledge transfer study (mostly SMEs) staff did not report any learning from persons in academia or a research institution. The same work shows a clear preference for interpersonal learning, supporting the assertion that opportunity to converse with and question an expert in person is something worth having.

Part of the rationale behind this project was to capture knowledge from those soon to retire. An excellent example is Professor Kevin Potter, co-lead on this project with wide industrial experience and teacher of the pilot units, who has now retired. His anecdotes were considered a highlight of the taught units. With his permission, video clips of him telling some of the most amusing and enlightening stories will be embedded into the slides so that future students can benefit. In general, it would be worth recording these units- and perhaps interviews with experts- for this purpose.

Videos, lectures slides and supplementary material can however be made available for later reference online. Most participants in the trial units thought they would refer back to notes and handouts, so making this material available for reference is clearly of value and would be helpful to anyone choosing to attempt assessments. An alternative would be an online resource which could reflect technical developments after the delegate attendance. As the courses are likely to be delivered on a paid-for basis, it may be advisable to keep this in a secure area and provide a login to participants. Options such as time-limited logins and companies paying for access to the material should be discussed when the future IP model is decided.

Assessments, academic qualifications and accreditation

Assessment

The role of **assessment** is dependent on context. Within an established degree programme, assessment is an essential prerequisite of the formal qualification. However, in the context of Continuing Professional Development (CPD), many delegates to short courses may not appreciate the value of assessment and certification for consolidation of their learning and formal recognition of achievement, rather than simply attendance. Further, where the CPD is in a commercial/industrial context, the institution funding the training may simply want an enhanced skill set on the shop floor now without enabling time for formal assessment.

If a formal qualification at Master's level is to be offered, there is unlikely to be time to carry out full assessments during the unit delivery- and as an optional element, this would not be a good use of time. Participants choosing to pursue the qualification would therefore carry out the assessment remotely over a set period of time, ideally in and linked to their employer business.

Current assessment methods may be suitable for use here, or able to be modified.

Integrated Learning Package, University of Bolton

One model that has been suggested is the Integrated Learning Package, developed by the University of Bolton for remote assessments. This is a three part assessment which may have different deadlines for each part and can be carried out remotely. The assignment includes a list of references. The lecturer is expected to offer help via email, phone and post during the period of assessment. The assignments are typically limited to 4000 words.

Part 1, typically 20 marks out of a total 100, contains short answer questions and/or simple problem-solving exercises, intended to develop comprehension of the material. This should be relatively easy for the student and act as a confidence booster.

Part 2, typically 30 marks out of a total 100, consists of in-depth problems with structured questions, intended to develop problem solving skills, and/or a comprehension exercise from a published scientific work.

Part 3, typically 50 marks out of a total 100, is a case study where the student must work independently to propose a solution to a novel problem. This may be an essay question and/or a laboratory study.

For the unit 8-6 Fire and Post-Fire Performance of composites, Professor Kandola suggested a slightly altered version of the ILP could be used as follows: *"The ILP consists of two components in which Part 1 examines the candidate's basic understanding of the concept, principles and awareness of the module, Part 2 probes and investigate selected classes of answers which are designed to reflect deep understanding of the subject."*

Industrial Doctorate Centre Assessments, University of Bristol

Written and computational assignments

The majority of units are assessed using written assignments. These are mostly in-depth questions requiring the student to demonstrate understanding and independent thinking. They may be structured with sub questions or not, and often require reference to external sources of knowledge. Some references are given, but students are also expected to conduct independent literature based research.

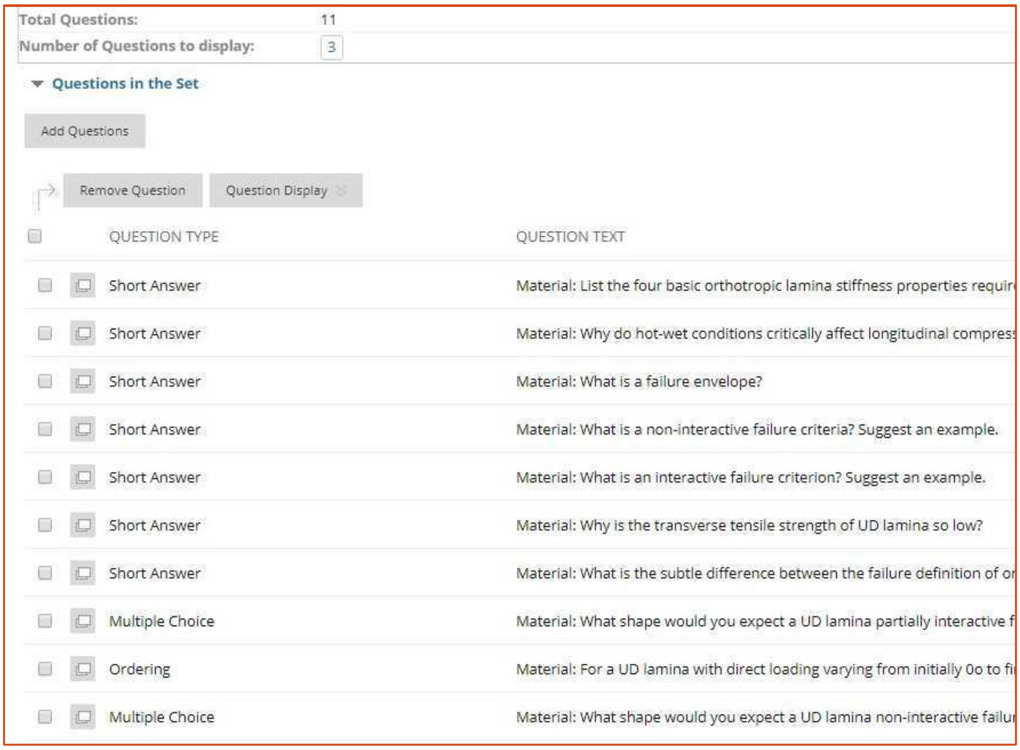
Written assignments may include industry focused tasks such as producing risk assessments or manufacturing instruction sheets. They may also involve writing up, interpreting and discussing practical work carried out during the unit.

Students may be required to carry out computer based tasks such as simulations and report on these, the simulation files may also be submitted as part or all of the material to be assessed. This requires the students to have access to software licenses and appropriate computing resources. For the IDC, laptops and limited licenses are supplied to students.

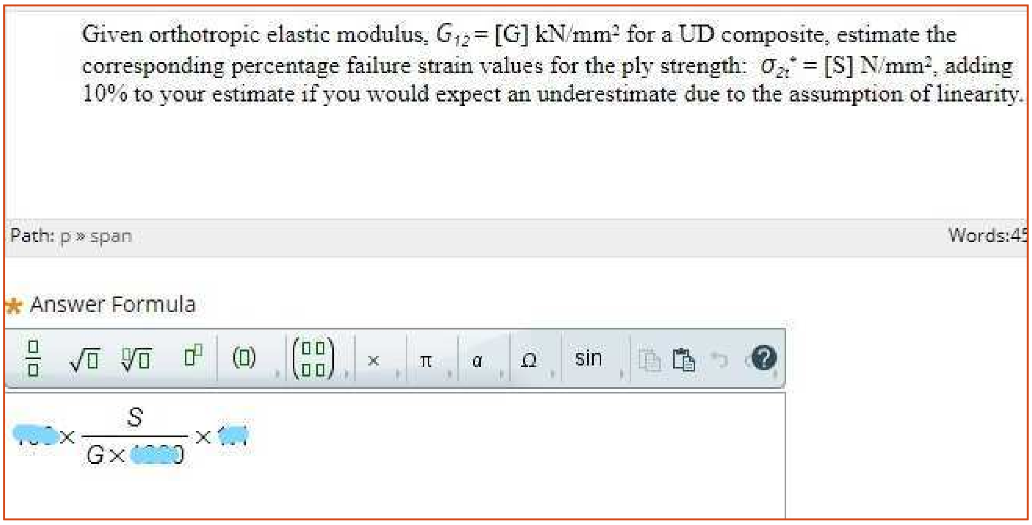
Presentations and videos

Some units are partially assessed by presentations delivered in person or by videos submitted by the student. It is possible that presentations could also be delivered over an online conferencing system, but this requires the student and assessor to be available at the same time. Student produced videos negate this problem but does not allow the assessor an opportunity to question the student on their presented work. Student feedback suggests alternatives to written assignments are welcome.

Online test[16]



The Laminate Analysis unit is assessed by an online test in Blackboard. The lecturer creates a large number of possible questions, which are placed into pools. The system then draws questions from each pool to create a test according to a plan specified by the lecturer (e.g. 2 questions from pool 1, 3 questions from pool 2). Mathematical questions can be varied according to simple formulae, where the lecturer sets a range of values for each variable. This ensures that two students taking the test simultaneously cannot work together, as they each receive different questions. Questions can include photos (Flickr), videos (YouTube) and presentations (SlideShare).



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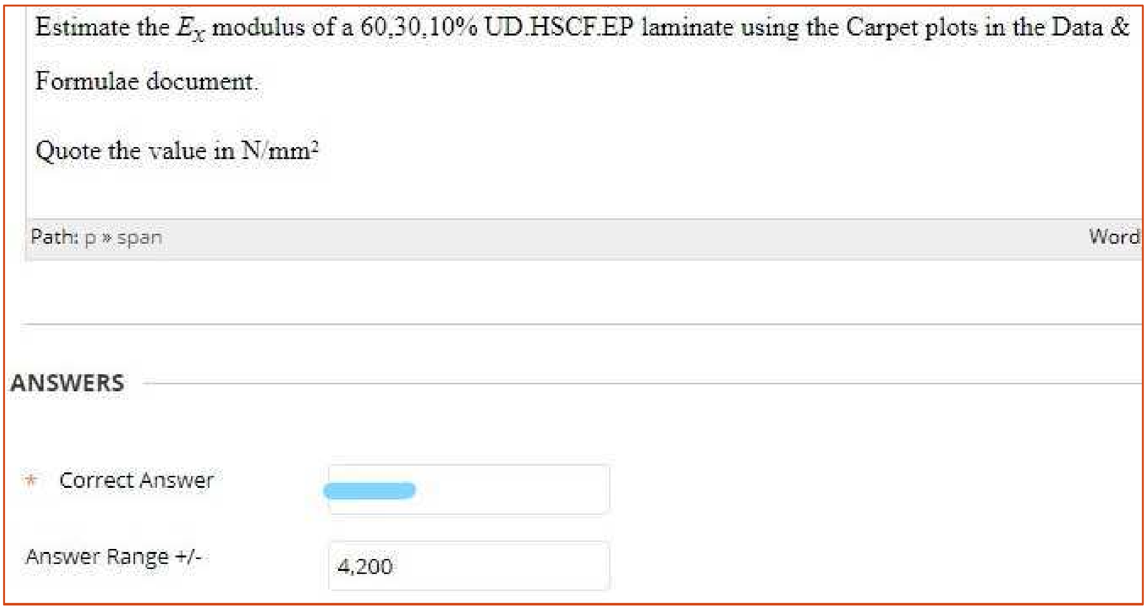
[16] Screenshots from online test included with the kind permission of Dr Ian Farrow

The students take the test at the same time, remotely, though there is an option to delete marks and allow a student a second try if technical problems such as internet connection failure affect their result. The nature of the test system means a second try is highly unlikely to be the same as the first.

The first part of the test is short questions, which can be automatically marked. Types of question include inputting numerical answers, multiple choice, selecting true or false statements, fill in the blank, matching pairs of statements or ordering lists.



The second part of the test is a set of questions on a case study. The students are able to read information pertaining to the case study prior to the test. Here the students are expected to carry out calculations, draw sketches etc by hand. They then write a summary of their method and any numerical answers in the online test. It is also possible to photograph their handwritten notes for uploading. This part of the test cannot be marked automatically.

The students are given a trial version of the test, with a limited number of questions, so that they can familiarise themselves with the interface. If there are sufficient questions in each pool, they are unlikely to encounter repeat questions in the assessment.

It is possible to restrict the time available, and to allow extra time for students who require this.

Student feedback has been largely positive, though some felt the test too long for the time available. The group (6 persons) were evenly split as to whether they preferred a test like this or a written assessment. Technical comments included difficulty in inputting equations, which can be solved by uploading photographs of handwritten work, and a request to be allowed to move back and forth between questions rather than completing them in order. Blackboard help pages suggest that this is possible, but using this setting means the test cannot be resumed if the student is accidentally disconnected or presses the back button in their browser.

Undergraduate Assessments, University of Plymouth

The University of Plymouth assesses undergraduates through both examinations and coursework.

The examination for Composites Design and Manufacture lasts three hours and consists of 6-8 equal value questions, from which the student may select 4. Each question is split into numerous sub-questions, some of which test memory of key facts while higher mark items require discussion and/or calculation, allowing the student to demonstrate their understanding.

The coursework for the same unit involves practical group work followed by an individual report.

The Composites Engineering coursework is an extended design, build and test project. Each student creates a specification and theoretical design and manufacturing plan. The group then agree the design, manufacturing and testing programme, before carrying this out, which may include numerous prototypes. Reports are then written individually.

Home Laboratory, Queen Mary University of London

QMUL's Home Laboratory is a piece of experimental coursework which can be carried out in the home without specialised equipment. The example provided involves creation of ice composites using easily available fibres and a home freezer. These ice composites are assessed and compared to unreinforced ice through mechanical testing. The student is expected to design and construct apparatus for quantifiable tests using items found around the home, encouraging inventive problem solving and practical skills, then to write up the result in the manner of a scientific paper, with consideration of relevant theory.

MSc Composites assessment, University of the West of England

This coursework is split into two tasks. The first requires the student to construct a spreadsheet for various laminate analysis calculations. This spreadsheet is submitted for marking as the task 1 deliverable and used in task 2.

The second task is a design exercise, requiring independent reading and application of theoretical concepts. The student is expected to use the aforementioned spreadsheet and Abaqus in the design process and should submit a report and the Abaqus files.

The coursework can be carried out remotely provided the student has access to the required software on a computer capable of running it.

Continuing Professional Development *vs* exit qualifications for HEFCE Catalyst multi-site M-level qualification

There is a desperate need for composites Training Needs Analysis (TNA) to quantify industrial demand and hence indicate numbers of students/delegates likely to participate in the training. The industry driver is to enhance the skill set on shop floor, often as a short-term solution. Similarly design office workers may need understanding of limitations set by design and manufacture. In that context any individual modules may address the immediate needs of the employer without commitment to a full formal qualification. A certificate of attendance may be adequate for the employer, although some acknowledgement of competence may be preferred.

The employee with a commitment to career progression may be interested in more formal recognition of the Continuing Professional Development, especially when working towards Incorporated/Chartered Engineer/Environmentalist/Scientist status. Existing CPD courses- mostly not at Masters level- may be recognised for these schemes.

Where CPD is delivered by an academic institution, accumulation of credits may result in Post-Graduate Certificate (PGCert ~ 60 credits), Post-Graduate Diploma (120 credits) or Masters (180 credits). Masters is often split 120:60 (MSc: Master of Science) or 70:110 (MRes: Master of Research) with the ratio indicating the credit split for taught modules:dissertation. The latter, with taught modules combined with a workplace-based dissertation, may be an attractive model for industrial delegates.

For personnel in small- or medium-sized enterprises (SME), there will be a significant challenge in completing a formal academic qualification on the timescales required by the academic institution. 30 two-day units is of the order of 25% full-time equivalent (FTE) of the working year which could be a significant reduction in manpower for such a company, even spread over a two-year part-time study, and especially where that individual is the only person in the company with specific technical expertise.

It is implicit in the collaborative model under consideration here that modules may be delivered in more than one institution, especially for specialist modules hosted by institutions with unique facilities, e.g. fire at Bolton. This raises the Spectre of a student having a collection of credits from different institutions The classic models for inter-institution collaboration were Credit Accumulation and Transfer Scheme (CATS) or Integrated Graduate Development Scheme (IGDS, formerly funded by EPSRC as a vehicle to provide modular part-time education/training for graduates in industry but the scheme closed about 15 years ago).

It may be necessary for the awarding institution to consider either of Accreditation of Prior Certificated Learning (APCL) for credits gained elsewhere, or Accreditation of Prior Experiential Learning (APEL) for appropriate experience, respectively for a student to gain an exit qualification. Many universities recognise European Credit Transfer System (ECTS) credits for courses involving study abroad, where 1 ECTS credit is considered equal to 2 UK credits.

Technical Accreditation Scheme, Warwick

WMG at Warwick hosts the Jaguar Land Rover Lifelong Learning Academy[17]. This is intended to tackle a skills gap in the automotive industry, with a focus on hybrid vehicles, embedded and electronic systems.

Jaguar Land Rover worked with WMG and nine other universities to deliver M-level training modules for engineers, which can result in an MSc. The Technical Accreditation Scheme[18] uses experts to deliver five day units based on campus, using practical and classroom exercises alongside other teaching styles, with discussion encouraged.

17 https://warwick.ac.uk/newsandevents/pressreleases/jaguar_land_rover_launches_lifelong_learning_academy_with_wmg_as_partner1/

18 http://wrap.warwick.ac.uk/67863/

Some taught elements were delivered by experts from industry. It was stated that their relative lack of teaching experience limited the effectiveness of some teaching, but their experience was very valuable and students gave favourable responses when asked. Where a course is taught by a person from a particular company, to students from that company, it can become too specific to their business processes.

The assessment required students to find and talk to technical experts within their company. This facilitates development of a knowledge network and is worth considering when developing assessments for the composites curriculum. While the assessment was stated to be compulsory, submission rates varied considerably between modules. It was found that many students did not appreciate the value of the assessment in consolidating their learning, hence those who were not interested in an academic qualification considered it unnecessary.

This scheme was later expanded to include other employers through the Advanced Skills Accreditation Scheme[19], which follows a similar model of individual units to that suggested for the composites curriculum. Each unit is individually accredited, and these credits can be added up towards a postgraduate qualification.

Modules are valued at 10 or 15 CATS (Credit Accumulation and Transfer Scheme) points, with 1 point equal to 10 hours of study, and each module has a compulsory assessment. The student registers for individual modules at the appropriate host universities. A Chosen University, which must provide a minimum of 50% of the total CATS points, can recognise modules from the other universities through the CATS scheme and award an appropriate qualification. However, we have been informed that the CATS scheme is no longer available.

Degree Apprenticeship

A level 7 degree apprenticeship or 'mastership' may be a suitable option for some students, though the units should remain open to those who wish to study through a different route. Degree apprenticeships combine on the job learning with study, often through day release or block release. The apprentice must spend at least 20% of their time studying. The degree apprenticeship funding might cover a Post-Graduate Diploma, the student would have the option of taking an extra 60 credits for an MSc, perhaps through a dissertation based on their employment.

It may be possible to create a new standard for Composites Manufacture, or to add modules to the existing Postgraduate Engineer degree apprenticeship standard. This standard suggests a typical apprenticeship should last 24-30 months[20]. (). The University of the West of England (UWE) currently offer this apprenticeship[21].

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[19] http://northernautoalliance.com/wp-content/uploads/2012/03/ASAS-Leaflet-June-2012.pdf

[20] https://www.instituteforapprenticeships.org/apprenticeship-standards/post-graduate-engineer/

[21] https://www1.uwe.ac.uk/business/degreeapprenticeships/currentdegreeapprenticeships/postgraduateengineer.aspx

Degree apprenticeships are cheaper for SMEs (5% of the cost) but the majority of students on UWE's existing Postgraduate Engineer degree apprenticeship are from larger companies. The aforementioned issue with loss of a worker's time for SMEs may be an issue.

Accreditation

The Institute of Materials, Minerals and Mining (IOM3), as the Professional Engineering Institution hosting the British Composites Society (BCS), provides **accreditation** for a list of degree programmes[22] including BEng/MEng, MSc or EngD. Accreditation is a lengthy process, involving a team of professional engineers visiting the institution hosting the course to assess the content and quality of that provision. A graduate of the accredited institution will then have a clear route to professional status, including Chartered Engineer (Engineering Council), Chartered Environmentalist (Society for the Environment) or Chartered Scientist (Science Council).

The aspiration in developing a network of UK universities collaborating to permit accredited continuing professional development in composites across a number of well-found institutions raises the spectre of a student having a collection of credits from different institutions. Our understanding is that, unfortunately, the former Credit Accumulation and Transfer Scheme (CATS) scheme is no longer available as a functional option. University of Plymouth AD T&L Science and Engineering advised *"Academic credit can only be awarded by one institution at a time, so it looks like you will need to set-up some kind of arrangement where a group of universities formally agree to recognise one another's credits as leading to an award made by one of them (as awards can't be made by the group, just by the institution that the student enrols with)".* There may be scope for one or more institutions to operationalise such a scheme, recognising credits from other institutions by Accreditation of Prior Certificated Learning (APCL), and/or maybe Accreditation of Prior Experiential Learning (APEL).

An alternative model might be the Integrated Graduate Development Scheme (IGDS). This scheme was formerly funded by the UK Engineering and Physical Sciences Research Council (EPSRC) as a vehicle to provide modular part-time education/training for graduates employed in industry. The delegates (students) gained industrially orientated and market-driven postgraduate training whilst remaining in full-time employment. There were about fifty IGDS programmes available covering all sectors of industry, but the scheme seems to have ended approximately 15 years ago.

Making It Happen

Next Steps

The group have discussed various options for continuing the work, including an NPL-NCC led proposal:

"The UK Composites Curriculum project was an important first step in an overall program aimed at closing the skills gap in the Advanced Composites industry. With a predicted growth in the use and application of advanced composites, there is an urgent need to address well documented industrial skills shortages.

Funded by HEFCE, the Phase 1 project scope was to identify what materials should be included in the curriculum and to produce a framework for a masters program. This required a review of composites

[22] https://www.iom3.org/academic-accreditation-list

teaching as is currently being delivered in the UK, supported by international benchmarking. The Phase 1 project also sought to identify industrial and academic demand, to substantiate and validate skills requirements.

A phase 2 programme is now proposed, to continue development when Phase 1 completes in August 2019. The phase 2 programme aims to create, plan and ultimately deliver training content based upon the 59 unit descriptions developed during Phase 1. In addition, the market intelligence gained from phase 1, namely industrial and academic demand and international benchmarking, is an important pointer to the success of phase 2 work. This would be used to prioritise material development, addressing the immediate needs and maximising impact for the benefit of UK industry.

Prior to any further work, a Phase 2 programme team will need to be created, inclusive of curriculum development partners, a Steering Group and a core Project Team. NCC and NPL, having complimentary composites technical capabilities and experience in developing and delivering accredited training courses, expressed an interest to and initiated work for formulating a Phase 2 Programme

The Phase 2 programme will develop Phase 1 deliverables into a full business proposal, outlining the key steps to the successful delivery. It will address the phased development of curriculum content over a 3-year period, completing in September 2022. It will coordinate the creation of these materials by consortia members commensurate with their abilities. It will also consider the commercial elements of development such as distribution of funding between consortia partners, challenges surrounding intellectual property and an appropriate mechanism of delivery to the industrial base." (Provided by NCC and NPL)

In addition to this, workshops to obtain a clearer demand signal from industry, following on from the initial work presented in this report, are planned for the autumn of 2019. Funding is available for two such workshops. This can be carried out in parallel with the NPL-NCC plan. It is likely that additional work may be needed in order to clarify the demand signal, which can be considered as part of phase 2. It is regrettably notable that obtaining a clear, quantitative demand for long term training needs is a difficult prospect across the wider engineering sector.

The most immediate next step is to create a business case for the future. Following on from this, the next phase will require collaboration agreements, which will likely be based on the legal advice commissioned as part of this project and may involve formation of a joint body. Constructing a framework for development and delivery of the units; including the legal requirements; which is acceptable to all parties, will require a small project team.

NCC and NPL have expressed interest in working on this and may be able to fund some staff time. The Universities of Bristol and Plymouth wish to remain involved but at the close of this project will no longer be able to employ staff for this purpose unless other funding is obtained.

Legal Advice

A detailed legal advice note has been received from Veale Wasbrough Vizards LLP. They narrow down the options for structuring the future project to two:

1) Contractual Collaboration, with a specified Lead Member. A Consortium Agreement would define the legal rights and responsibilities of the Members. As the Consortium is not a legal body, any agreements, ownership of IP or applications for funding would have to be made by one or more Members on behalf of

the Consortium. It is recommended that a Lead Member, preferably the organisation responsible for the day to day running of the project, be chosen who would be responsible for this.

2) Joint Venture forming a Limited Liability Company. The LLC would be owned and controlled by the Members, with day to day running overseen by a board of directors. The LLC may or may not have charitable status, VWV recommend that unless the LLC is expected to make significant profits- which would be tax free on charitable activities, the greater flexibility afforded by not having charitable status is preferable.

In either case it is recommended that foreground IP- e.g. teaching material developed for this curriculum- should sit with one party, either the Lead Member or LLC, either by assignment or an irrevocable exclusive license. If an exclusive basis is not considered appropriate, it is recommended that other use of the material be restricted, with permitted use- such as academic and research purposes- set out in the Consortium Agreement.

The advice note details a number of points which should be considered before any decisions are made.

Comparable case: Economics Core Curriculum

This[23] is a collaborative curriculum with contributions by a number of different organisations. Unlike the proposed Composites Curriculum, the Economics courses are used in early undergraduate courses and schools as well as a postgraduate course for students from diverse backgrounds. Material is provided online rather than delivered in person by subject matter specialists.

Despite the differences between this and the proposed Composites Curriculum, there are numerous similar challenges. It may be possible to learn from their experiences.

Governance: A registered charity (England and Wales) for the public benefit, overseen by Trustees who manage the business and guide the strategic planning. Day to day running is carried out by a Charity Secretary and operations are carried out by the Production Team. Some work is carried out by volunteers and interns. If a Limited Liability Company is set up to deliver the Composites Curriculum it may be registered as a charity, but does not have to be.

Copyright: CORE's material is open access and available under Creative Commons Attribution-NonCommercial-NoDerivs license, meaning it can be freely distributed worldwide for non-commercial purposes provided the source is credited, but the material may not be changed in any way or used commercially. This is an option for the Composites Curriculum if all participating organisations agree. This license keeps control over the material, so it cannot legally be modified and presented under the source's branding and prevents others from legally profiting by it. However, it is available worldwide, which may be an issue if the consortium or a funding body wish to restrict the material to the UK. It should be noted that reading teaching material alone is not considered a substitute for learning from an expert in person, as discussed above, so if the materials were to be distributed there would still be a great deal of value in attending the units. It appears from the website that the material is licensed by the charity rather than separately by contributors, as in the model suggested by VWV.

Funding: Grant funded from a variety of sources, at least some of which are specific to provision of open access learning material. Choosing to use Creative Commons may allow the Composites Curriculum to

[23] https://www.core-econ.org/

apply for such funding, but it is not known whether or not delivery of courses in person, for which a fee must be charged in order to cover costs, would be permitted.

Teaching collaboration: Material is provided by subject matter experts from numerous institutions. This includes a jointly authored textbook, available as an ebook. All authors and institutions providing material must agree to do so under the above Creative Commons license.

Online reference materials: An ebook, lecture slides, videos, quizzes, a glossary of terms and interactive spreadsheets are available to students online, along with references for facts stated in the ebook. There are YouTube links to narrated lectures.

Assessments: As the material is provided for use by universities and schools, assessments are carried out separately by each institution. This negates any issue of transferring credits but may be more difficult for the Composites Curriculum as the assessments will need to be set and marked by subject matter experts, most likely those who produce and deliver the course materials.

Branding: All material is provided under the CORE brand rather than that of the contributing institution. The Composites Curriculum project may wish to consider a similar approach, for consistency and to ensure no individual institution's brand is subject to risk by being associated with material beyond their control.

Future Funding

Creation of a business case which can be used to apply for future funding has been discussed with the National Composites Centre. It is considered likely that a clear vision of the future and a detailed roadmap will be needed, with an option for numerous small projects, separately funded, to contribute to the long-term plan.

Two workshops to investigate industrial demand are funded under a separate project, the results will be beneficial to both that project and this.

The University of Plymouth have applied for a Knowledge Transfer Partnership with a composites SME which follows on from this work and develops it further. "To develop and embed a new business process to intrinsically capture and document internal knowledge and experience, to enable training and knowledge transfer to support business growth within the composite manufacturing sector." The application is for funding of £180k for 24 months.

Issues encountered in the composites industry may be reflected in the wider digital engineering sector. It is therefore possible that work on this project could be used as a pilot for a new approach which may benefit a larger range of businesses.

Catapult Fellowship?

One option explored is the possibility of an individual fellowship under HVMC. An initial proposal, shown in the appendices, was submitted to HVMC. The proposed Fellow would be an academic, funded to drive this project forward as their full-time job, including sourcing funding for a collaborative next stage. They would be able to work alongside the NCC-NPL team or any alternative group.

Evaluation of Project

This project has lasted longer than originally planned, largely due to staffing difficulties in the early stages. It has however delivered everything in the original business case and more, with the addition of example units, multiple pilots, shared resources and detailed feedback.

The project is grateful to HEFCE Catalyst for the initial funding. However, as this unique funding opportunity is no longer available, it is difficult to define a clear plan for continuation of the work. The need is well-defined, the suggested curriculum a good starting point- but to make it a reality both funding and a core team are needed to ensure the good work so far does not go to waste.

Engagement with academics has been broadly good, with representatives of a small number of universities present at all meetings and many others in contact via email or attending one meeting only. Unit descriptions have been written by a variety of people, but overall the bulk have been contributed by the two co-leads, Professor John Summerscales and Professor Kevin Potter. Increasing levels of contribution, and critical appraisal, from other institutions would be welcome.

Engagement with industry has been more difficult. Only one company has provided staffing figures which could be used to improve our estimate of future requirements and there have been very few responses to requests for comment. Through NCC, attendance at the third pilot units were good, with Tolerancing, Variability and Defects over-subscribed. NCC has acted as a representative of industry through most of the project and conducted reviews of the unit descriptions on this basis.

Conclusion

This project has delivered on its aims and provides a good basis for future development of industrially focused teaching at Masters level in the composites industry. The proposed curriculum covers a wide range of topics, intended to be taught by experts in the field to industrial participants as short, 2-day courses in response to demand.

Any future work requires funding. it is recommended that continuation should start by constructing a joint body and IP agreement that all institutions are happy to sign up to, followed by a plan for delivery of the units and funding their development.

Appendices

Appendix 1- Financial Summary

HEFCE Composites Curriculum Development Project, Provisional Budget Summary August 2019

Income	**HEFCE Catalyst**			**£ 200,000**
Salaries		***Actual to date***	***In process***	***Total***
	Academic	£ 20,614.82	£ 12,672.26	£ 33,287.08
	Hourly paid teachers	£ 4,940.40	£ -	£ 4,940.40
	Professional/Admin	£ 4,963.33	£ -	£ 4,963.33
	Temporary staff service	£ 20,392.74	£ 3,746.41	£ 24,139.15
	Sub-total	**£ 50,911.29**	**£ 16,418.67**	**£ 67,329.96**
Non salary		***Actual to date***	***In process***	***Total***
	Travel and Subsistence	£ 217.00	£ -	£ 217.00
	Casual staff costs	£ 25,917.41	£ 834.02	£ 26,751.43
	Equipment/Consumables	£ 1,836.73	£ -	£ 1,836.73
	Catering & other food	£ 566.19	£ -	£ 566.19
	Room hire costs	£ 2,689.00	£ -	£ 2,689.00
	UWE Unit Development	£ 7,678.00	£ -	£ 7,678.00
	NPL Unit Development	£ -	£ 50,700.00	£ 50,700.00
	Copyright legal advice	£ -	£ 4,200.00	£ 4,200.00
	NCC material review and hosting of pilot units	£ -	£ 15,330.00	£ 15,330.00
	Sub-total	**£ 38,904.33**	**£ 71,064.02**	**£ 109,968.35**
Plymouth costs		***Actual to date***	***In process***	***Total***
	Travel	£ 5,000.00	£ -	£ 5,000.00
	Staff	£ 11,394.00	£ -	£ 11,394.00
	Estates	£ 1,731.00	£ -	£ 1,731.00
	Indirect costs	£ 6,875.00	£ -	£ 6,875.00
	Sub-total	**£ 25,000.00**	**£ -**	**£ 25,000.00**
Total spending	**Grand total**			**£ 202,298.31**

Shortfall + **-£ 2,298.31**

+ shortfall covered by Institution's contribution

Please note that staff costs are paid in arrears, so the final payment will be made in September. Timesheets have been approved. A final summary can be provided once all pay and invoices clear.

Appendix 2- Curriculum Mapping Data

Institution	Course Type	Course name	Composites compulsory or optional
Bath	MEng	Aerospace Engineering	Optional
Bath	MEng	Integrated Design Engineering	Optional
Bath	MEng	Mechanical Engineering	Optional
Bath	MEng	Mechanical with Automotive Engineering	Optional
Birmingham	MSc	Materials Science & Engineering	Mixed
Birmingham	MRes	Science & Engineering of Materials	Mixed
Birmingham	MEng	Aerospace Engineering	Mixed
Birmingham	MEng	Materials Science and engineering	Mixed
Bolton	MSc	Advanced Materials	Compulsory
Bristol	PhD	Advanced Composites	Mixed
Bristol	EngD	Composites Manufacture	Compulsory
Bristol	MEng	Aerospace Engineering	Compulsory
Cambridge	MASt	Materials Science	
Cranfield	MSc	Advanced Materials	Compulsory
Cranfield	MSc	Aerospace Materials	Compulsory
Cranfield	MSc	Aerospace Manufacturing	Optional
Cranfield	Short Course	Modelling, Simulation and Monitoring of Composites Cure	Compulsory
Cranfield	Short Course	Composite Material Structures	Compulsory
Cranfield	Short Course	Introduction to Composite Materials	Compulsory
Cranfield	Short Course	Functional Composites Materials	Compulsory
Cranfield	Short Course	Composites Integration Repair and Joining	Compulsory
Cranfield	Short Course	High Performance Composite Structures and Components - Materials, Design and Manufacturing Techniques	Compulsory
Cranfield	Short course	Materials Selection	Compulsory
Cranfield	Short Course (Online)	Principles of Materials	Compulsory
Cranfield	MSc/PG Diploma/PG Certificate	Aerospace Materials/Aircraft Engineering	Compulsory
Cranfield	Short Course	Toughening of Polymer Resins	Compulsory
Cranfield	Short Course	Sustainable Composites Manufacturing and Industrial Applications	Compulsory
Cranfield	Short Course	Introduction to Aircraft Stress Analysis	Compulsory
Cranfield	Short Course	Nanomaterials and advanced composites	Compulsory

Edinburgh	MEng	Mechanical Engineering	Mixed
Edinburgh Napier	MEng	Mechanical Engineering	Mixed
Exeter	BEng	Materials Engineering	Compulsory
Exeter	MSc	Materials Engineering	Compulsory
Glasgow	MEng	Aeronautical Engineering	Compulsory
Glyndwr	MSc/PG Diploma	Composite Material Engineering	Compulsory
Glyndwr	BEng	Composite Design	Compulsory
Hertfordshire	Short Course	Composite Repair	Compulsory
Imperial	MSc	The Science, Technology and Engineering Application of Advanced Composites	Compulsory
Imperial	MSc	Advanced Materials Science and Engineering	Compulsory
Imperial	MEng	Mechanical Engineering	Compulsory
Imperial	MEng	Aeronautical Engineering	Compulsory
Kingston University	BEng/MEng	Aerospace Engineering	Compulsory
Kingston University	BEng/MEng	Mechanical Engineering	Compulsory
Kingston University	MEng/MSc	Mechanical Engineering	Compulsory
Kingston University	MSc	Advanced Industrial and Manufacturing Systems	Optional
Kingston University	MSc	Aerospace Engineering	Compulsory
Kingston University	BEng	Aircraft Engineering	Compulsory
Liverpool	MSc	Advanced Aerospace Engineering	Optional
Liverpool	MEng/BEng	Mechanical Engineering	Optional
Liverpool	Meng/BEng	Aerospace Engineering	Compulsory
Loughborough	PG Cert/Diploma/MSc	Materials Science and Technology	Mixed
Loughborough	Diploma/MSc/PG certificate	Polymer Science and Technology	Compulsory
Manchester	MSc	Textile Technology (Technical Textiles)	Optional
Manchester	MSc	Polymer Materials Science and Engineering	Mixed
Manchester	MSc	Advanced Engineering Materials	Mixed
Manchester	MEng	Materials Science and Engineering	Compulsory
Newcastle	MEng	Civil and Structural Engineering	Compulsory
Newcastle	MEng	Mechanical Engineering	Compulsory
Nottingham	MSc	Additive Manufacturing and 3D Printing	Mixed
Nottingham	MSc	Advanced Materials	Compulsory
Nottingham	MSc	Mechanical Engineering	Compulsory

Oxford Brookes	MSc	Motorsport Engineering	Compulsory
Oxford Brookes	MSc	Mechanical Engineering	Mixed
Oxford	MEng	Materials Science	Compulsory
Plymouth	BEng/MEng	Mechanical Engineering with Composites	Compulsory
Portsmouth	MSc	Mechanical Engineering	Compulsory
QMUL	MEng	Materials Science and Engineering	Compulsory
QMUL	MEng	Aerospace Engineering	Mixed
Sheffield	MSc/MRes	Aerodynamics and Aerostructures	Optional
Sheffield	MSc/MRes	Advanced Manufacturing Technologies	Optional
Sheffield	MSc	Polymers for Advanced Technologies	Compulsory
Sheffield	MSc/MEng	Polymers and Polymer Composite Science and Engineering	Compulsory
Sheffield	MSc/MEng	Aerospace Materials	Compulsory
Solent	BEng	Ship Science/Yacht and Small Craft	Compulsory
Southampton	MEng/ MSc	Yacht and Small Craft	Optional
Strathclyde	MSc	Advanced Mechanical Engineering with Materials	Compulsory
Surrey	MSc	Advanced Materials	Compulsory
Surrey	Short Course	Composite Materials Technology: Design, Technology and Performance	Compulsory
Surrey	Short Course	Characterisation of Advanced Materials	Compulsory
Surrey	Short Course	Polymers: Science, Engineering and Applications	Compulsory
Surrey	Short Course	Materials Under Stress: An Introduction to Fracture Mechanics and Fatigue	Compulsory
Surrey	Short Course	The Science and Technology of Adhesive Bonding	Compulsory
Surrey	Short Course	Introduction to Composite Materials	Compulsory
Ulster	MSc	Advanced Composites and Polymers	Compulsory
Ulster	PG diploma	Advanced Composites and Polymers	Compulsory
UWE	Short Course	Advanced Manufacturing	Compulsory
UWE	MEng	Mechanical Engineering/Automotive Engineering/Aerospace Engineering	Compulsory
UWE	Short Course	Aircraft Structural Design and Stress Analysis	Compulsory
Warwick	MSc	Analytical and Polymer Science	Compulsory
Warwick	MEng	Automotive Engineering	Compulsory
Warwick	MEng	Mechanical Engineering	Compulsory

Institution	Eng/tech undergrads	Eng/tech taught postgrads
Bath	2715	190
Birmingham	2175	630
Bolton	610	45
Bristol	1840	250
Cambridge	1460	110
Cranfield	0	1735
Edinburgh	1565	245
Edinburgh Napier	915	150
Exeter	910	190
Glasgow	1625	295
Glyndŵr	700	55
Hertfordshire	1385	150
Imperial	3585	1035
Kingston	1740	230
Liverpool	1940	155
Loughborough	3455	640
Manchester	3675	1245
Newcastle	2040	785
Nottingham	2835	310
Oxford Brookes	685	100
Oxford	645	0
Plymouth	1350	80
Portsmouth	2170	425
QMUL	1230	120
Sheffield	4165	710
Solent	1120	70
Southampton	2450	410
Strathclyde	3715	630
Surrey	1855	445
Ulster	1245	130
UWE	1850	110
Warwick	1535	1240
sum	59185	12915
per year	14796.25	10977.75
joining workforce	8137.9375	4061.7675
	4 years total	30% are part time

University of BRISTOL UNIVERSITY OF PLYMOUTH

Appendix 3- International Benchmarking Data

Course	Type	Uni	Country	Compulsory	Manufacturing topic(s)?	Industry project?	Other industry?	Type	Time
Master of Engineering	M.Eng	Australian National University	Australia	No	Optional	No	No	Full time	1 yr
Materials Engineering	MSc	KU Leuven	Belgium	No	Optional	Optional	No	Full time	2 yrs
Chemical and Materials Engineering	MSc	Vrije Universiteit Brussel	Belgium	No	Optional	Optional	Company visits	Full time	2 yrs
Advanced Materials Manufacturing	MEL	University of British Columbia	Canada	Yes	Yes	No	No	Full time	1 yr
Mechanical Engineering	MSc	Aarhus University	Denmark	No	No	Optional	No	Full time	2 yrs
Advanced Composite Engineering and Science	M-ENG	Centrale Nantes	France	Yes	Yes	Optional	No	Full time	2 yrs
Advanced Materials	MSc	University of Bordeaux	France	No	No	Optional	No	Full time	2 yrs
Advanced Materials for Innovation and Sustainability	**MSc**	**Bordeaux/ Grenoble/ Aalto/ Darmstadt/ Liège**	**France/ Finland/ Belgium/ Germany**	**No**	**No**	**Optional**	**Industrial partners**	**Full time**	**2 yrs**
Aerospace Engineering	MSc	École Centrale de Lyon	France	No	No	No	No	Full time	2 yrs
Éco-conception des Polymères et Composites	**MSc**	**Université Bretagne Sud**	**France**	**Yes**	**Yes**	**Optional**	**Option to work second year**	**Full time OR split with industry**	**2 yrs**
Textile Engineering	**MSc**	**RWTH Aachen University**	**Germany**	**Yes**	**Yes**	**Optional**	**Based at ITA**	**Full time**	**2 yrs**
Verbundwerkstoffe	**MSc**	**PFH Stade Hansecampus**	**Germany**	**Yes**	**Yes**	**While working**	**Collaborators nearby**	**Short blocks plus thesis**	**1.5 yrs**

NATIONAL COMPOSITES CENTRE — hefce HIGHER EDUCATION FUNDING COUNCIL FOR ENGLAND — ACMC

Chemical Engineering Programme	M.S.	King Abdullah University of Science and Technology	Saudi Arabia	No	No	No	No	Full time or part time	1.5 yrs
Composite Materials	MSc	Luleå University of Technology	Sweden	Yes	Yes	No	Connected to needs of partner companies	Full time	2 yrs
Materials Engineering	MSc	Chalmers University	Sweden	No	No	No	Links with a list of companies	Full time	2 yrs
Materials Science and Engineering	MSc	Koç University	Turkey	No	No	No	No	Full time	?
Composites Manufacturing and Engineering	Grad Cert	University of Delaware	USA	Yes	Yes	No	Designed for industry	Online	?
Composite Materials	Grad Cert	University of Delaware	USA	Yes	Yes	No	Designed for industry	Online	?
Mechanical Engineering	MSc	University of Delaware	USA	No	Optional	No	Access above courses	Full time or Online	1.5-2 yrs

Course	Notes
Master of Engineering	Composite materials optional 6 unit (of 48) course including design exercise, research project, practical manufacturing techniques.
Materials Engineering	Polymers and Composites is a 'career oriented' 12 credit option of a total 120 credits. 4 courses: Composites Manufacturing, Mechanics of Heterogenous Materials, Polymer Processing, Design and Applications of Polymers and Composites- including a group case study to "(re)engineer a polymer or a composite component" assessed by report.
Chemical and Materials Engineering	Two profiles: process technology and materials. Composites are mentioned in the materials profile. There is an option to receive credit points for an internship (6 -10 ECTS). Little composites content.
Advanced Materials Manufacturing	Combination of engineering and business courses, 1 course on advanced composite materials compulsory, also an optional composite materials course and more general courses which will include some composites. Learning through case studies, group projects, experiments and demonstrations.
Mechanical Engineering	Mentions many industrial examples. Fracture Mechanics (10ECTS) and Mechanics of Composite Materials (5ECTS) are one of the 'specialised study' options (not compulsory). Some of the electives, e.g. wind energy systems, are likely to involve composites too. There is an option to carry out a project in collaboration with a company or research group.
Advanced Composite Engineering and Science	Includes 1 semester (30 credits of 120 total) of almost all composites courses- constituents and processes, characterization, processing modelling, structures, manufacturing system organization and multi-physics modelling for processes. Also a project and language. Thesis may be done through industrial internship.
Advanced Materials	Chemistry focused. Optional module on innovative and composite materials (6 credits of total 120). 6 month training period in academic or industrial laboratories.
Advanced Materials for Innovation and Sustainability	**Chemistry department. Double degree by two universities- an example of co-operation on teaching, with one year at each. Internships and industrial projects available. Has industrial partners. Composites and ceramics an optional year 2 speciality, taught in Bordeaux. Practical work and a project.**
Aerospace Engineering	Option for Dynamic and Sustainability of Composite Materials. One optional module focuses on the design process for an aircraft or a rocket engine. The final research project is 6 months. General manufacturing (e.g. Lean) is covered but not composites specific options, though it may be included under 'process-product-performances'.
Éco-conception des Polymères et Composites	**Second year of the course has an option for alternating between the university and industry, 2 weeks in each, with second semester entirely in the company. Appears to be open to employees as well as students. The student has a salary for their work and it gives access to a job. First year study includes some manufacturing technologies. If the 'alternating' option is not taken there is still an option for an internship.**

Textile Engineering	**Student chooses to either follow the 'coursework' route, focused on practical and applied engineering in industry, or 'research', for specialising in an R&D field. Very composites focused. Optional courses include industrial items such as factory planning and production metrology for the coursework route. Located at Aachen's Institute for Textile Technology.**
Verbundwerkstoffe	**Targeted at students with professional experience, who want to gain a qualification through professional development. 60 ECTS part time or 90 ECTS full time over three semesters. Units are taught in blocks over 7-17 days and weekend courses for the first two semesters. The third semester is for the thesis. Advertises 'up to date content provided by professors with practical experience. Collaborative partners (Airbus, DLR, Fraunhofer) near campus. Management content included. Composites and industry focus.**
Chemical Engineering Programme	Chemical engineering focus, unit on physical chemistry of macromolecules includes composites. May go on to a PhD, industry sponsored students can study part time.
Composite Materials	120 credits. Composite materials, multifunctional polymer composites: advanced processing and manufacturing, biocomposites and composites: design and numberical methods are compulsory, a total of 30 credits. Some optional courses are likely to include significant composites content. Linked to companies SICOMP and ABB who are recruiting.
Materials Engineering	120 credits. States that courses are "closely linked to the industry". Run by academic staff from across different departments. Composite and Nanocomposite materials is an optional course. States that they cooperate with large and small companies, listing Volvo, Volvo cars, GKN Aerospace, SAAB, SKF, SCA, Sandvik, SWEREA and ARCAM.
Materials Science and Engineering	Multicomponent polymeric systems is an optional course including composites. Polymer composites are also included in other courses such as surface and interface properties of materials, thermomechanical properties of materials and introduction to polymer science. 30 credits or 21 plus a thesis are needed.
Composites Manufacturing and Engineering	Online course, all composites. Exercises using software are included, but no lab sessions. These courses are also available to those doing an MSc.
Composite Materials	Designed for engineering/science professionals who are new to composites. States it is all online, but some of the courses seem very practical in nature and would need lab work.
Mechanical Engineering	30 credits. Can be done entirely online. Composites options from the above courses are available, but not compulsory. Thesis is optional.

Course	Link
Master of Engineering	https://programsandcourses.anu.edu.au/course/ENGN6511
Materials Engineering	https://onderwijsaanbod.kuleuven.be//opleidingen/e/CQ_50545818.htm#activetab=diploma_omschrijving
Chemical and Materials Engineering	http://www.vub.ac.be/en/study/chemical-and-materials-engineering/programme
Advanced Materials Manufacturing	https://www.grad.ubc.ca/prospective-students/graduate-degree-programs/master-of-engineering-leadership-advanced-materials-manufacturing
Mechanical Engineering	http://kandidat.au.dk/en/mechanicalengineering/
Advanced Composite Engineering and Science	https://www.ec-nantes.fr/graduate/masters-/advanced-composite-engineering-and-science-m-eng-aces--189374.kjsp
Advanced Materials	https://www.u-bordeaux.com/Education/Study-offer/Masters-in-English/Chemistry/Advanced-Materials
Advanced Materials for Innovation and Sustainability	**https://www.u-bordeaux.com/Education/Study-offer/Masters-in-English/Chemistry/Advanced-Materials-for-Innovation-and-Sustainability-AMIS**
Aerospace Engineering	https://www.ec-lyon.fr/en/academics/master-programs/international-master-programs/masters-aeronautics-space
Éco-conception des Polymères et Composites	**https://www.ecoconceptionpolymerescomposites.com/**
Textile Engineering	**https://www.academy.rwth-aachen.de/en/education-formats/msc-degree-programmes/textile-engineering**
Verbundwerkstoffe	**https://www.pfh-university.com/studies/technology/composites-master.html**
Chemical Engineering Programme	https://pse.kaust.edu.sa/study/academic-programs/chemical-engineering/Pages/academics-information.aspx
Composite Materials	https://www.ltu.se/edu/program/TMKOA/TMKOA-Kompositmaterial-master-1.83577?l=en
Materials Engineering	http://www.chalmers.se/en/education/programmes/masters-info/Pages/Materials-Engineering.aspx
Materials Science and Engineering	https://gsse.ku.edu.tr/en/graduate-programs/materials-science-and-engineering/ders-tanimlari/

Composites Manufacturing and Engineering	http://me.udel.edu/academics/graduate/graduate-certificate-in-composites-manufacturing-engineering/
Composite Materials	https://me.udel.edu/academics/graduate/graduate-certificate-in-composite-materials/
Mechanical Engineering	http://me.udel.edu/academics/graduate/

Appendix 4- Sample feedback form

HEFCE Composites Curriculum Development Project

Trial unit feedback questionnaire

This questionnaire is anonymous and participation is entirely voluntary. Answers to these questions will be used to improve the trial teaching material. Data will be entered onto a spreadsheet on a University of Bristol computer and the paper questionnaires will be shredded so that no record of your handwriting is kept. Anonymous data may be shared with other institutions to develop and improve composites courses in the UK.

You are not obliged to answer every question. Please continue on another piece of paper if you wish to write more. All feedback gratefully received, please give your honest opinion. Swearing is permitted.

1) Please mark your level of agreement with the following statements:

	Disagree -------Agree				
Statement	**-2**	**-1**	**0**	**1**	**2**
The course was interesting					
The content made sense					
The topics we covered are applicable to my work					
The industrial examples were a valuable inclusion					
Seeing and holding composite parts and moulds was beneficial					
I have more questions now than before attending the course					
The lecturer was easy to understand					
The slides are well laid out					
I am likely to refer back to the handouts and/or my notes from today					
I had sufficient opportunity to ask questions					
There was too much content for the time available					
I would like to learn more about advanced composites					
My company would benefit from training in advanced composites					
An optional assignment would help to consolidate what I have learned					
I would be interested in adding up points from courses like this towards an academic qualification					

2) Did you enjoy *An Introduction to the History and Manufacture of Composite Materials?* Circle an answer.

Yes No Meh Rubbish Amazing!!

3) Was the level of the content right for you? Please mark on the scale below where it fits.

Knew it all before | Easy | Perfect | Difficult | Over my head

P.T.O. →

4) Tell us about your favourite part of the course

5) Tell us about your least favourite (or the most boring) bit

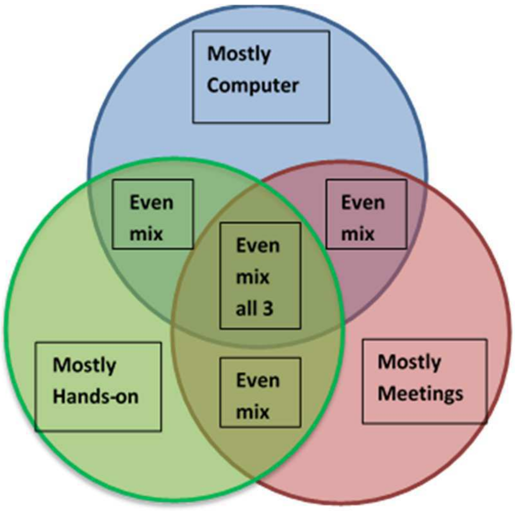
6) Is there a particular topic or theme you would like to know more about?

7) What do you think we need to improve and why? Can you suggest how to do this?

8) Overall, how would you rate this course out of ten? /10

Your current job (for our reference only)

Please do not name your employer



9) Does your current job involve advanced composites (polymer resin + fibre reinforcement)? Y/N
10) Please mark where on the diagram your job fits →
11) Approximately how many years of experience do you have working with advanced composites?
12) Approximately how many years of experience do you have in engineering and science overall?

Thank you for your time

Appendix 5- Full data from unit feedback forms

Feedback from HEFCE Unit trials

Results of questionnaires handed out at the UWE and NCC 2019 pilots.
The questionnaires are copied here for reference.
Charts may be filtered by course to compare the trial units.

Results are arranged by question.
The first set of worksheets displays the results graphically (scrolling required)
the second includes all the data.
Demographic data, from the 'current job' section, is displayed alongside the question 8 charts and can be used to filter the tables and charts.

Abbreviations:
Compjob? = does your current job involve advanced composites?
Yrscomp = number of years experience with advanced composites
Yrseng = number of years experience in science/engineering

Job type? As marked on Venn diagram
Computer, Hands-on or Meetings
Mixtures C&H, M&C, H&M
Mix = mix of all three

Question 1: Agreement with the statements on a scale -2 to +2
Displayed as a coloured table
Graph showing 'agreement' (+1 or +2) with each coloured by Yrseng

Question 2: Enjoyment of the unit
Simple chart showing number of people choosing each option

Question 3: Level of the content
Simple chart coloured by Yrseng, answers categorised at data entry stage
Markers overlaid on scale showing position of all answers

Question 4: Favourite parts of the course
Simple chart showing favourite parts, paraphrased (see data worksheet)
Some people gave multiple answers, all are included

Question 5: Least favourite parts of the course
Simple chart showing least favourite parts, paraphrased (see data worksheet)
Some people gave multiple answers, all are included

Question 6: Topics they would like to know more about
Simple chart, topics categorised (see data worksheet)
Some people gave multiple answers, all are included

Question 7: Suggestions for improvement
Simple chart, paraphrased (see data worksheet)
Some people gave multiple answers, all are included

Question 8: Rating out of 10
Simple chart
Demographics shown as pie charts for job type and yrseng

Question 1

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Statement	Agree?
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The content made sense	0
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	0
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	1
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	0
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	1
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	-1
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	-1
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	1
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	0
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	0
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The content made sense	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	2

UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	0
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The content made sense	1
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	0
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2

UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	1
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	0
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	1
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The content made sense	1
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	-2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	0
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	0
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	-2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	-2
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	1

UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The content made sense	1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	-1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	2
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	0
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	-2
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	0
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	0
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The content made sense	1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	-1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	-2

UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	-1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	0
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	-2
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	-1
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	-1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The content made sense	2
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	0
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	-1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	1

UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	-1
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	0
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	1
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The content made sense	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	0
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	0
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	1
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The content made sense	1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	-1

UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	0
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	-2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	-1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	1
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	0
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	-2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	0
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	-1
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The course was interesting	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The content made sense	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The topics we covered are applicable to my work	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The industrial examples were a valuable inclusion	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	I have more questions now than before attending the course	-1
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The lecturer was easy to understand	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	The slides are well laid out	1
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	I am likely to refer back to the handouts and/or my notes from today	1

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UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	I had sufficient opportunity to ask questions	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	There was too much content for the time available	1
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	I would like to learn more about advanced composites/other topics in composites manufacturing	2
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	My company would benefit from (more) training in advanced composites	0
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	An optional assignment would help to consolidate what I have learned	0
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The course was interesting	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The content made sense	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	0
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	0
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	There was too much content for the time available	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	0
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The course was interesting	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The content made sense	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	0

TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	There was too much content for the time available	-2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	-1
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	0
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The course was interesting	1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The content made sense	1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	The slides are well laid out	0
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	1

TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The course was interesting	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The content made sense	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	I have more questions now than before attending the course	1
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	0
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The course was interesting	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The content made sense	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	The slides are well laid out	0

TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	There was too much content for the time available	-2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	0
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The course was interesting	1
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The content made sense	1
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	1
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	I have more questions now than before attending the course	2
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	The slides are well laid out	0
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	2
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	There was too much content for the time available	1
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	Blank
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	Blank
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	Blank
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The course was interesting	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The content made sense	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2

TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	The slides are well laid out	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	0
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	2
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The course was interesting	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The content made sense	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	The slides are well laid out	-1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	0
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	0
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2

TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The course was interesting	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The content made sense	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	0
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The course was interesting	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The content made sense	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	The slides are well laid out	1

TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	There was too much content for the time available	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	2
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The course was interesting	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The content made sense	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	The slides are well laid out	-1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	0
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	There was too much content for the time available	0
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	1
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The course was interesting	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The content made sense	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	2

TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The lecturer was easy to understand	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	There was too much content for the time available	-1
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	2
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	0
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The course was interesting	1
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The content made sense	0
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	-1
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	I have more questions now than before attending the course	0
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The lecturer was easy to understand	0
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	The slides are well laid out	0
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	1
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	-2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	There was too much content for the time available	2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	1
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	1

TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	1
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	0
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The course was interesting	1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The content made sense	1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The topics we covered are applicable to my work	-1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The industrial examples were a valuable inclusion	2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	I have more questions now than before attending the course	-2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The lecturer was easy to understand	1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	The slides are well laid out	1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	I am likely to refer back to the handouts and/or my notes from today	0
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	I had sufficient opportunity to ask questions	2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	There was too much content for the time available	2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	I would like to learn more about advanced composites/other topics in composites manufacturing	0
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	My company would benefit from (more) training in advanced composites	1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	An optional assignment would help to consolidate what I have learned	-1
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	I would be interested in adding up points from courses like this towards an academic qualification	Blank
PC1	Y	Mix	20	30	Production Costing	The course was interesting	2
PC1	Y	Mix	20	30	Production Costing	The content made sense	1
PC1	Y	Mix	20	30	Production Costing	The topics we covered are applicable to my work	1
PC1	Y	Mix	20	30	Production Costing	The industrial examples were a valuable inclusion	2
PC1	Y	Mix	20	30	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
PC1	Y	Mix	20	30	Production Costing	I have more questions now than before attending the course	1
PC1	Y	Mix	20	30	Production Costing	The lecturer was easy to understand	1
PC1	Y	Mix	20	30	Production Costing	The slides are well laid out	1

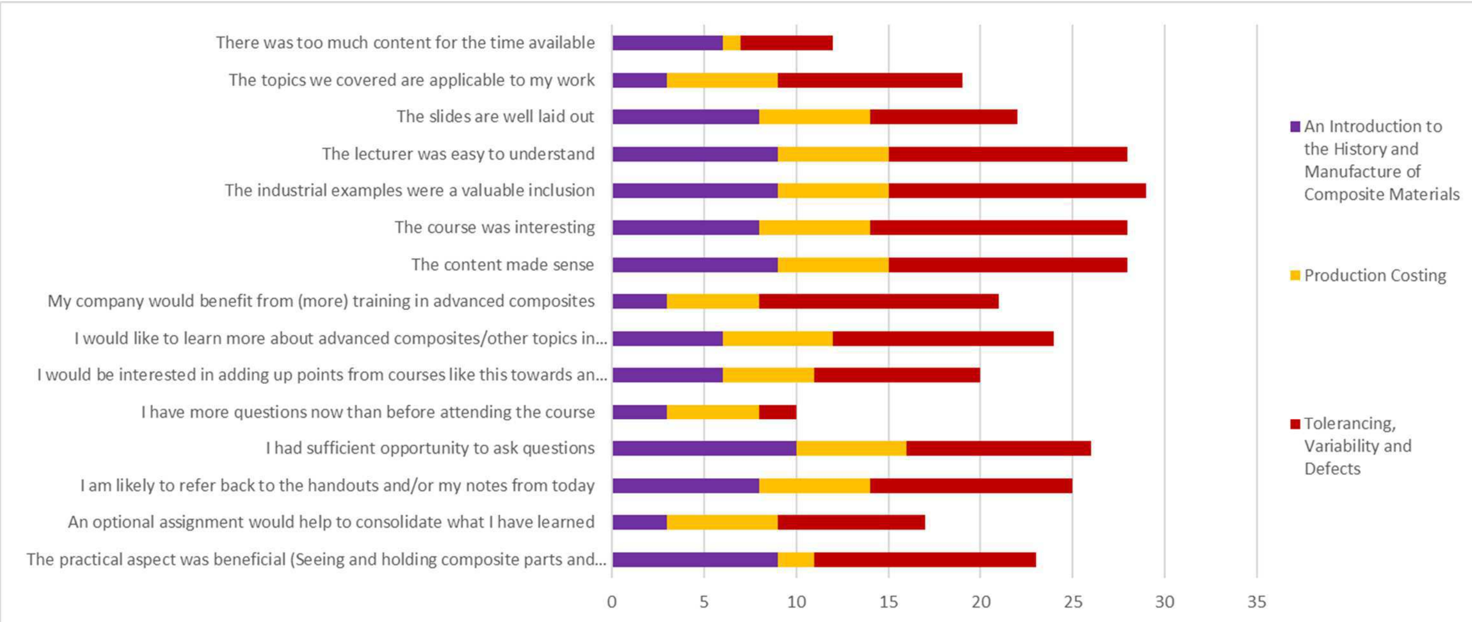
PC1	Y	Mix	20	30	Production Costing	I am likely to refer back to the handouts and/or my notes from today	2
PC1	Y	Mix	20	30	Production Costing	I had sufficient opportunity to ask questions	2
PC1	Y	Mix	20	30	Production Costing	There was too much content for the time available	1
PC1	Y	Mix	20	30	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	2
PC1	Y	Mix	20	30	Production Costing	My company would benefit from (more) training in advanced composites	Blank
PC1	Y	Mix	20	30	Production Costing	An optional assignment would help to consolidate what I have learned	2
PC1	Y	Mix	20	30	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	2
PC2	N	Computer	0	Too many	Production Costing	The course was interesting	2
PC2	N	Computer	0	Too many	Production Costing	The content made sense	2
PC2	N	Computer	0	Too many	Production Costing	The topics we covered are applicable to my work	2
PC2	N	Computer	0	Too many	Production Costing	The industrial examples were a valuable inclusion	2
PC2	N	Computer	0	Too many	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	2
PC2	N	Computer	0	Too many	Production Costing	I have more questions now than before attending the course	1
PC2	N	Computer	0	Too many	Production Costing	The lecturer was easy to understand	1
PC2	N	Computer	0	Too many	Production Costing	The slides are well laid out	2
PC2	N	Computer	0	Too many	Production Costing	I am likely to refer back to the handouts and/or my notes from today	2
PC2	N	Computer	0	Too many	Production Costing	I had sufficient opportunity to ask questions	2
PC2	N	Computer	0	Too many	Production Costing	There was too much content for the time available	0
PC2	N	Computer	0	Too many	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	2
PC2	N	Computer	0	Too many	Production Costing	My company would benefit from (more) training in advanced composites	2
PC2	N	Computer	0	Too many	Production Costing	An optional assignment would help to consolidate what I have learned	1
PC2	N	Computer	0	Too many	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	-2

PC3	Y	M&C	Blank	10	Production Costing	The course was interesting	2
PC3	Y	M&C	Blank	10	Production Costing	The content made sense	2
PC3	Y	M&C	Blank	10	Production Costing	The topics we covered are applicable to my work	2
PC3	Y	M&C	Blank	10	Production Costing	The industrial examples were a valuable inclusion	2
PC3	Y	M&C	Blank	10	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	Blank
PC3	Y	M&C	Blank	10	Production Costing	I have more questions now than before attending the course	2
PC3	Y	M&C	Blank	10	Production Costing	The lecturer was easy to understand	2
PC3	Y	M&C	Blank	10	Production Costing	The slides are well laid out	2
PC3	Y	M&C	Blank	10	Production Costing	I am likely to refer back to the handouts and/or my notes from today	2
PC3	Y	M&C	Blank	10	Production Costing	I had sufficient opportunity to ask questions	2
PC3	Y	M&C	Blank	10	Production Costing	There was too much content for the time available	-1
PC3	Y	M&C	Blank	10	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	2
PC3	Y	M&C	Blank	10	Production Costing	My company would benefit from (more) training in advanced composites	2
PC3	Y	M&C	Blank	10	Production Costing	An optional assignment would help to consolidate what I have learned	1
PC3	Y	M&C	Blank	10	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	1
PC4	Y	Computer	8	8	Production Costing	The course was interesting	1
PC4	Y	Computer	8	8	Production Costing	The content made sense	1
PC4	Y	Computer	8	8	Production Costing	The topics we covered are applicable to my work	1
PC4	Y	Computer	8	8	Production Costing	The industrial examples were a valuable inclusion	2
PC4	Y	Computer	8	8	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
PC4	Y	Computer	8	8	Production Costing	I have more questions now than before attending the course	2
PC4	Y	Computer	8	8	Production Costing	The lecturer was easy to understand	2
PC4	Y	Computer	8	8	Production Costing	The slides are well laid out	1
PC4	Y	Computer	8	8	Production Costing	I am likely to refer back to the handouts and/or my notes from today	2
PC4	Y	Computer	8	8	Production Costing	I had sufficient opportunity to ask questions	2
PC4	Y	Computer	8	8	Production Costing	There was too much content for the time available	-2

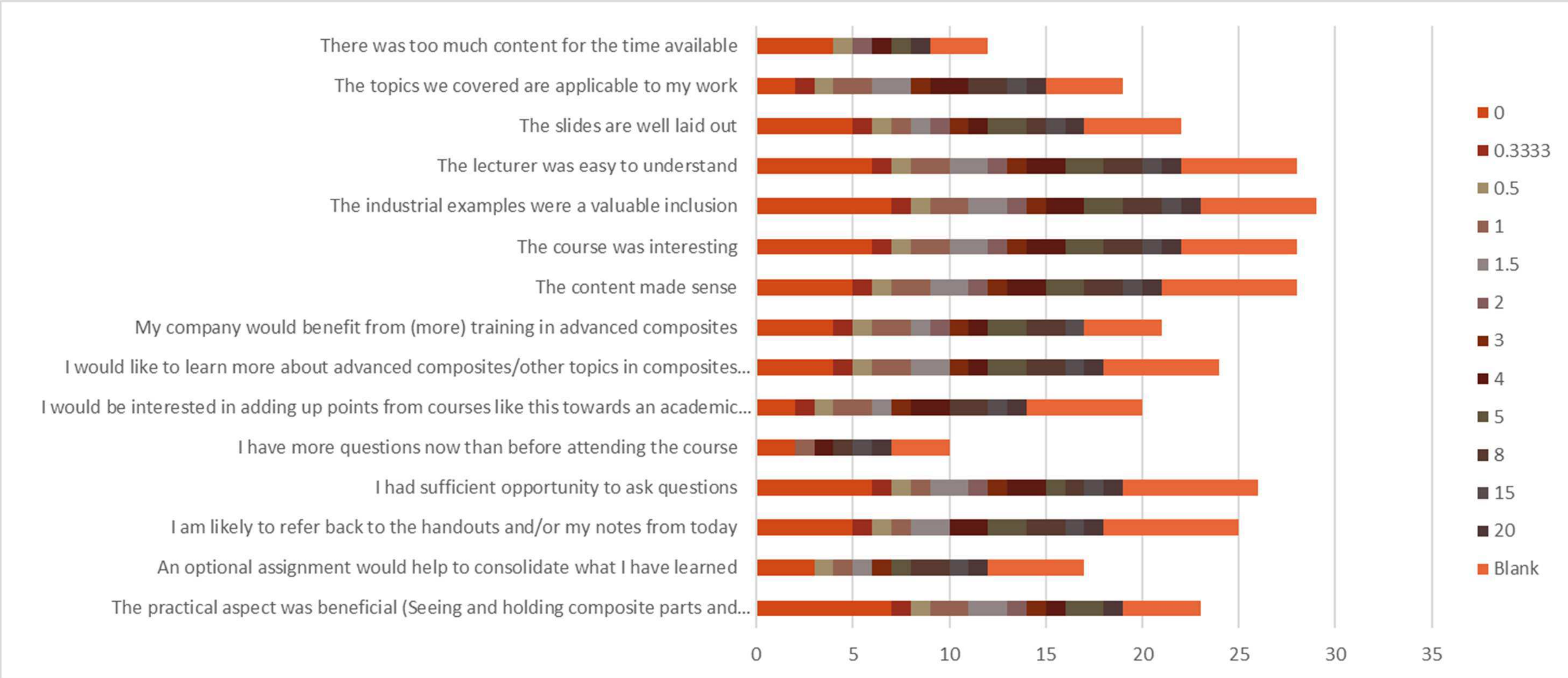
PC4	Y	Computer	8	8	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	2
PC4	Y	Computer	8	8	Production Costing	My company would benefit from (more) training in advanced composites	2
PC4	Y	Computer	8	8	Production Costing	An optional assignment would help to consolidate what I have learned	2
PC4	Y	Computer	8	8	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	2
PC5	Y	M&C	15	24	Production Costing	The course was interesting	2
PC5	Y	M&C	15	24	Production Costing	The content made sense	1
PC5	Y	M&C	15	24	Production Costing	The topics we covered are applicable to my work	1
PC5	Y	M&C	15	24	Production Costing	The industrial examples were a valuable inclusion	1
PC5	Y	M&C	15	24	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
PC5	Y	M&C	15	24	Production Costing	I have more questions now than before attending the course	1
PC5	Y	M&C	15	24	Production Costing	The lecturer was easy to understand	2
PC5	Y	M&C	15	24	Production Costing	The slides are well laid out	2
PC5	Y	M&C	15	24	Production Costing	I am likely to refer back to the handouts and/or my notes from today	1
PC5	Y	M&C	15	24	Production Costing	I had sufficient opportunity to ask questions	2
PC5	Y	M&C	15	24	Production Costing	There was too much content for the time available	-1
PC5	Y	M&C	15	24	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	1
PC5	Y	M&C	15	24	Production Costing	My company would benefit from (more) training in advanced composites	1
PC5	Y	M&C	15	24	Production Costing	An optional assignment would help to consolidate what I have learned	1
PC5	Y	M&C	15	24	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	2
PC6	Blank	M&C	Blank	Blank	Production Costing	The course was interesting	1
PC6	Blank	M&C	Blank	Blank	Production Costing	The content made sense	1
PC6	Blank	M&C	Blank	Blank	Production Costing	The topics we covered are applicable to my work	1
PC6	Blank	M&C	Blank	Blank	Production Costing	The industrial examples were a valuable inclusion	1
PC6	Blank	M&C	Blank	Blank	Production Costing	The practical aspect was beneficial (Seeing and holding composite parts and moulds/Hand layup exercise/Virtual Composites Company spreadsheet)	0
PC6	Blank	M&C	Blank	Blank	Production Costing	I have more questions now than before attending the course	0

PC6	Blank	M&C	Blank	Blank	Production Costing	The lecturer was easy to understand	2
PC6	Blank	M&C	Blank	Blank	Production Costing	The slides are well laid out	2
PC6	Blank	M&C	Blank	Blank	Production Costing	I am likely to refer back to the handouts and/or my notes from today	1
PC6	Blank	M&C	Blank	Blank	Production Costing	I had sufficient opportunity to ask questions	1
PC6	Blank	M&C	Blank	Blank	Production Costing	There was too much content for the time available	-1
PC6	Blank	M&C	Blank	Blank	Production Costing	I would like to learn more about advanced composites/other topics in composites manufacturing	1
PC6	Blank	M&C	Blank	Blank	Production Costing	My company would benefit from (more) training in advanced composites	1
PC6	Blank	M&C	Blank	Blank	Production Costing	An optional assignment would help to consolidate what I have learned	1
PC6	Blank	M&C	Blank	Blank	Production Costing	I would be interested in adding up points from courses like this towards an academic qualification	1

Additional graphs showing ratings of +1 and +2



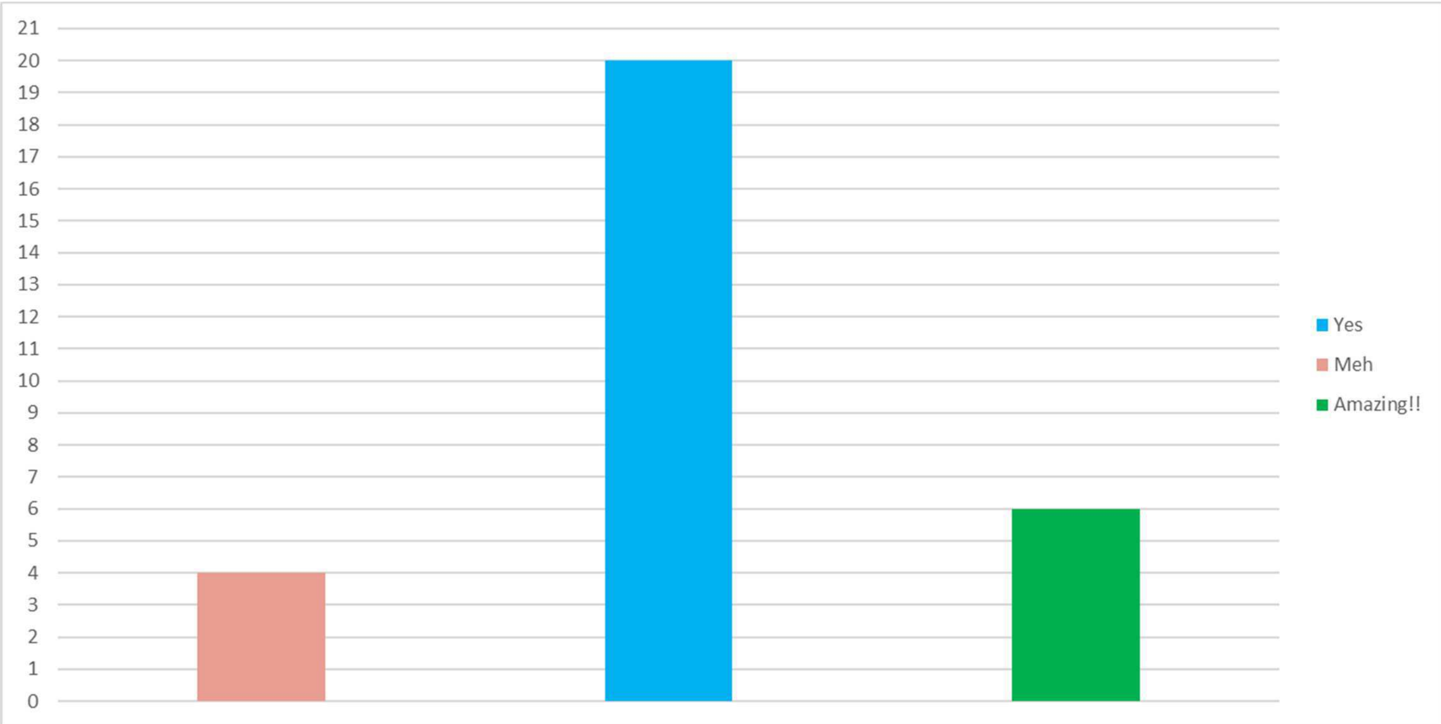
By years as an engineer



Question 2

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Enjoyment	Rate
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Amazing!!	2
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Amazing!!	2
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Yes	1
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Yes	1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Meh	0
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Meh	0
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Yes	1
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Amazing!!	2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Yes	1
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Amazing!!	2
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	Amazing!!	2
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	Yes	1
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Yes	1
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Yes	1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Yes	1
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Yes	1
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Yes	1
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Yes	1
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Yes	1
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	Yes	1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Yes	1
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	Amazing!!	2
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	Meh	0
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Meh	0

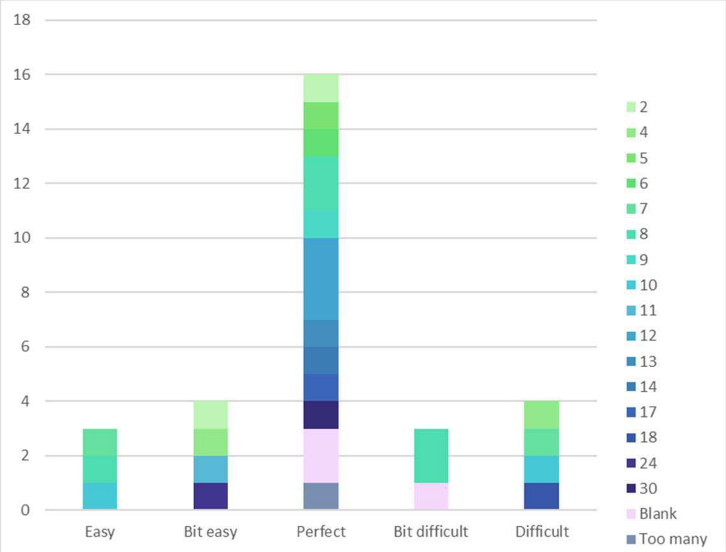
PC1	Y	Mix	20	30	Production Costing	Yes	1
PC2	N	Computer	0	Too many	Production Costing	Yes	1
PC3	Y	M&C	Blank	10	Production Costing	Yes	1
PC4	Y	Computer	8	8	Production Costing	Yes	1
PC5	Y	M&C	15	24	Production Costing	Yes	1
PC6	Blank	M&C	Blank	Blank	Production Costing	Yes	1



Question 3

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Was the level correct?	Y axis	Line
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	0
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	0.1
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Bit difficult	1.1	0
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	-0.1
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Bit difficult	1.5	0
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Bit difficult	0.9	0
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	0.2
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	-0.2
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Difficult	2	0
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Perfect	0	0.3
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	Perfect	0	-0.3
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	Perfect	0	0.4
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Bit easy	-0.9	0
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Difficult	2	0.1
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Perfect	0	-0.4
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Bit easy	-0.5	0
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Bit easy	-0.7	0

TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Perfect	0	0.5
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Perfect	0	-0.5
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	Difficult	2	-0.1
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Perfect	0	-0.5
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	Perfect	0	0.6
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	Difficult	2	0.2
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Easy	-2	0
PC1	Y	Mix	20	30	Production Costing	Perfect	0	-0.6
PC2	N	Computer	0	Too many	Production Costing	Perfect	0	0.7
PC3	Y	M&C	Blank	10	Production Costing	Easy	-2	0.1
PC4	Y	Computer	8	8	Production Costing	Easy	-2	-0.1
PC5	Y	M&C	15	24	Production Costing	Bit easy	-1.3	0
PC6	Blank	M&C	Blank	Blank	Production Costing	Perfect	0	-0.7



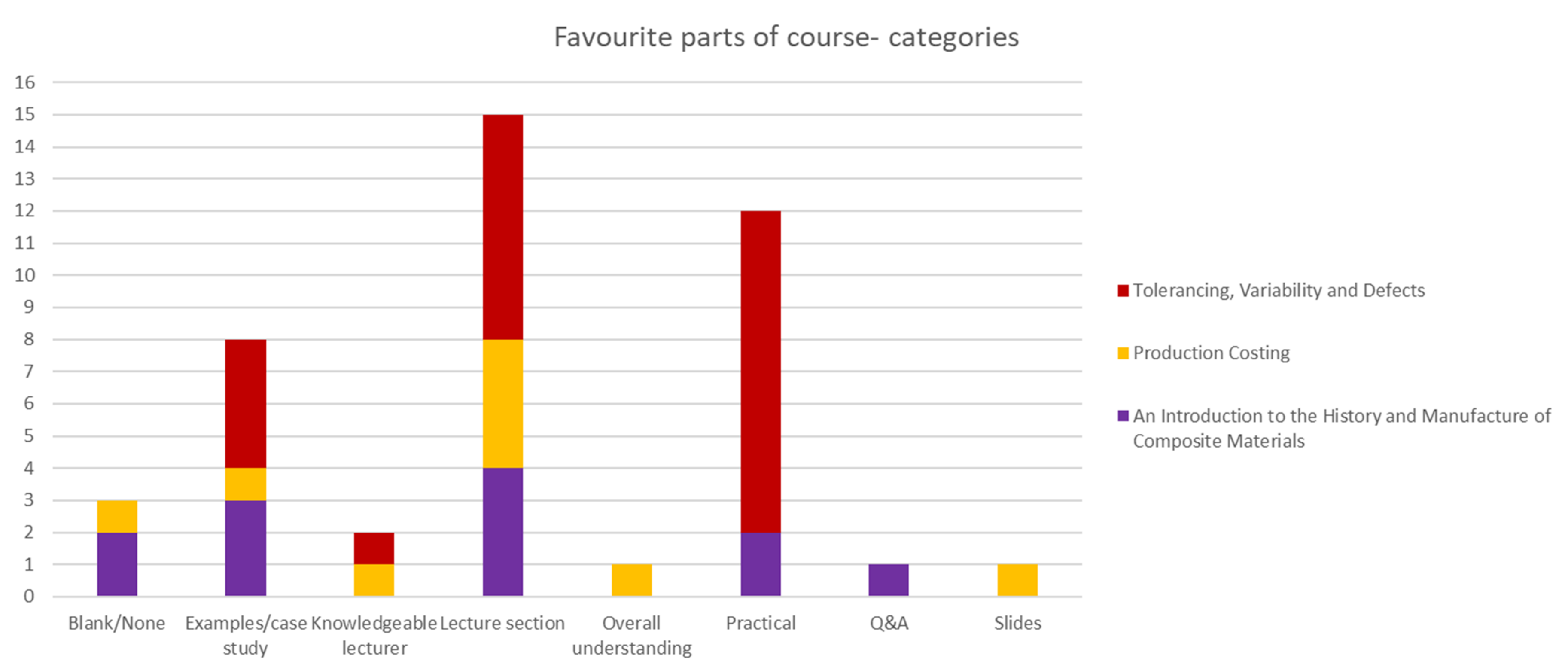
By years as an engineer

Question 4

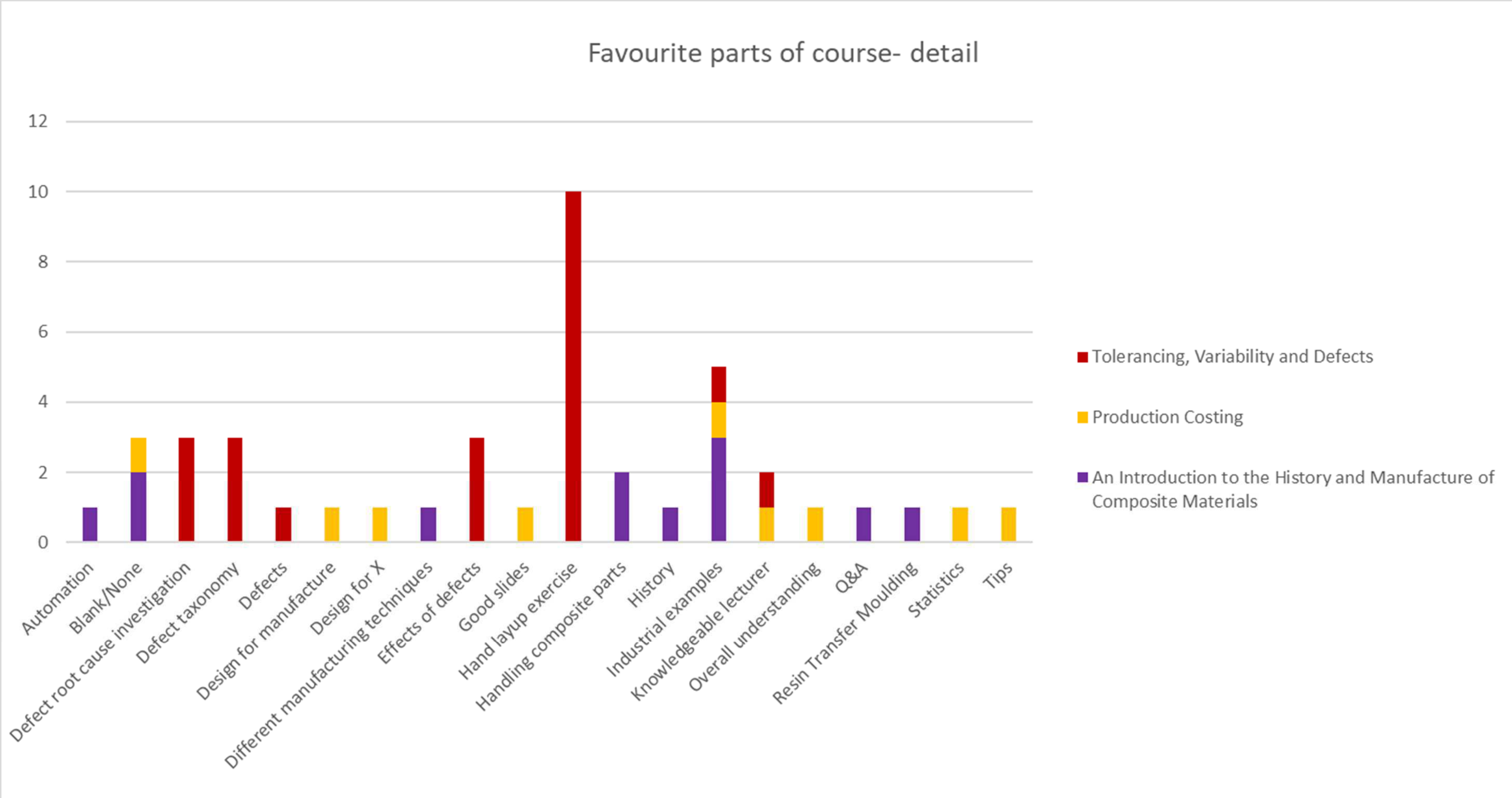
Person	Compjob ?	Job type	Yrs comp	Yrs eng	Course	Favourite part(s) of course	Category	Full quote
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	History	Lecture section	History and..
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Handling composite parts	Practical	handling the parts to learn from real material
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Industrial examples	Examples/case study	The applications to industry
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Q&A	Q&A	Q&A
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Handling composite parts	Practical	Hands on with composites
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Different manufacturing techniques	Lecture section	Description of different manufacturing techniques +
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Industrial examples	Examples/case study	examples
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Resin Transfer Moulding	Lecture section	RTM
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Automation	Lecture section	Automation within composite materials industrial processes

UWE1 0	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Industrial examples	Examples/case study	Industrial examples and connection to real life
TVD1	Y	Compute r	5	12	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Practical application in the lab helped a lot to understand the difficulties in the creation of lay-ups
TVD2	Y	Compute r	5	8	Tolerancing, Variability and Defects	Hand layup exercise	Practical	The manual layup part provided a good insight
TVD2	Y	Compute r	5	8	Tolerancing, Variability and Defects	Effects of defects	Lecture section	and the effects of defects section was interesting as it is relevant to my job
TVD3	Y	Compute r	Blank	2	Tolerancing, Variability and Defects	Hand layup exercise	Practical	The practical aspect was useful to see how difficult it -> to lay-up on geometry
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Practical exercise was good,
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Defect root cause investigation	Examples/case study	theoretical exercise and engagement was also good
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Defect root cause investigation	Examples/case study	Exercises,
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Hand layup exercise	Practical	hand lay up,
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Industrial examples	Examples/case study	industrial examples
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Defect taxonomy	Lecture section	Defect database - currently trying to figure out for project.
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Effects of defects	Lecture section	Effect of defects
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Defects	Lecture section	Defect related information, most applicable to my role (NDT Engineer)
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Defect taxonomy	Lecture section	Good overview handouts (A3 pages)
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Knowledgeable lecturer	Knowledgeable lecturer	Knowledgeable lecturer
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Effects of defects	Lecture section	Effects of defects section was pertinent to my day job.
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Lab exercise was very insightful into the difficulties in manufacture/layup.
TVD10	Y	Compute r	0.5	4	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Composite layup exercise
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Defect taxonomy	Lecture section	I liked the taxonomy of defects diagrams.

TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Defect root cause investigation	Examples/case study	The discussion using examples of pieces containing defects.
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Enjoyed the hand layup. Gave us a appreciation of how diffficult it was.
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Hand layup exercise
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Hand layup exercise	Practical	The practical section of laying up prepreg was very useful. This made it clear how difficult it is to avoid defects with some geometry
PC1	Y	Mix	20	30	Production Costing	Overall understanding	Overall understanding	Getting a better understanding of costing overall its easier to learn when you have time to concentrate ie not working
PC2	N	Computer	0	Too many	Production Costing	Blank/None	Blank/None	
PC3	Y	M&C	Blank	10	Production Costing	Design for manufacture	Lecture section	DFMA
PC4	Y	Computer	8	8	Production Costing	Industrial examples	Examples/case study	Industrial examples
PC4	Y	Computer	8	8	Production Costing	Design for X	Lecture section	& how DfX was applied
PC5	Y	M&C	15	24	Production Costing	Statistics	Lecture section	Some interesting & previously unknown stats.
PC5	Y	M&C	15	24	Production Costing	Tips	Lecture section	A few tips not currently adopted.
PC6	Blank	M&C	Blank	Blank	Production Costing	Good slides	Slides	Good slides
PC6	Blank	M&C	Blank	Blank	Production Costing	Knowledgeable lecturer	Knowledgeable lecturer	Knowledgeable lecturer



Favourite parts of course- categories
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Blank/None
Examples/case study
Knowledgeable lecturer
Lecture section
Overall understanding
Practical
Q&A
Slides
Tolerancing, Variability and Defects
Production Costing
An Introduction to the History and Manufacture of Composite Materials



Favourite parts of course- detail
12
10
8
6
4
2
0
Automation
Blank/None
Defect root cause investigation
Defect taxonomy
Defects
Design for manufacture
Design for X
Different manufacturing techniques
Effects of defects
Good slides
Hand layup exercise
Handling composite parts
History
Industrial examples
Knowledgeable lecturer
Overall understanding
Q&A
Resin Transfer Moulding
Statistics
Tips
Tolerancing, Variability and Defects
Production Costing
An Introduction to the History and Manufacture of Composite Materials

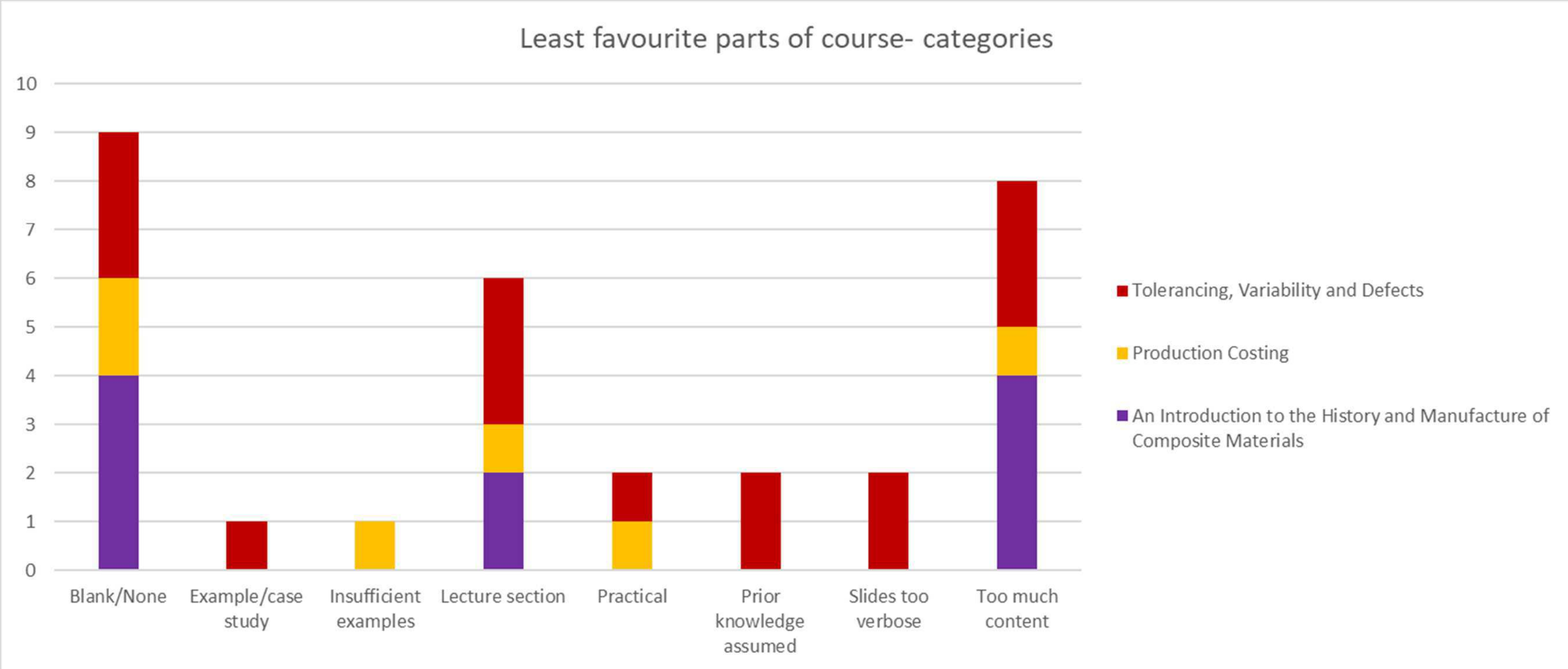
University of BRISTOL — UNIVERSITY OF PLYMOUTH

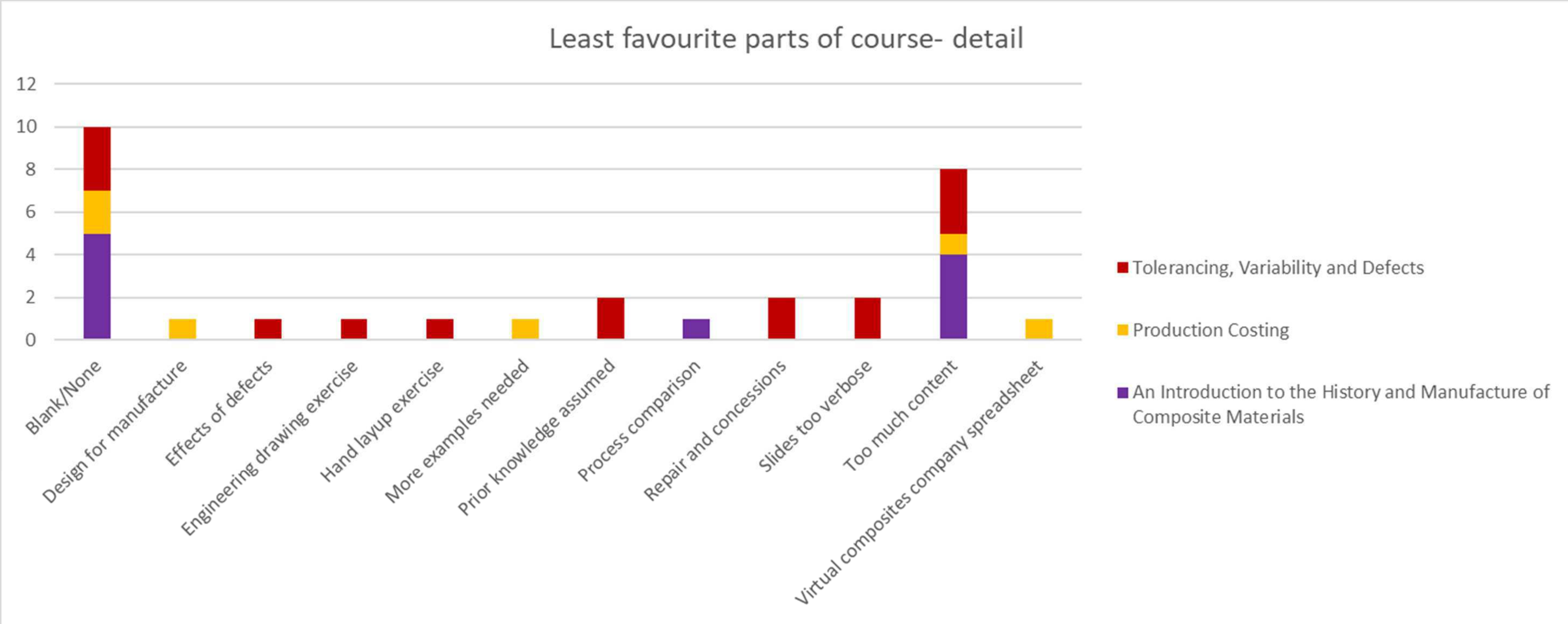
Question 5

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Least favourite part(s) of course	Category	Full quote
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Too much content	Too much content	A lot of info to fit into a day
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Too much content	Too much content	Understanding all the concepts, it was quite a lot to take in
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Process comparison	Lecture section	Process comparison
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Too much content	Too much content	Too much content for the timescale
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Too much content	Too much content	Don't have much experience with composite so a lot of information to take in.
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Lecture section	
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Blank/None	Blank/None	All good
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	Repair and concessions	Lecture section	Repair and concessions
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	Repair and concessions	Lecture section	Concessions section as this was the part that I was already most familiar with
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Slides too verbose	Slides too verbose	Large amount of words on the slides
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Too much content	Too much content	and a long time to be listening to a lot of information

TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Prior knowledge assumed	Prior knowledge assumed	Some of the content assumed prior knowledge
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Effects of defects	Lecture section	Effects of defects part was a bit of a slog but not too bad really
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Blank/None	Blank/None	
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Engineering drawing exercise	Example/case study	Assessment of engineering drawing
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Slides too verbose	Slides too verbose	Slides were very verbose (as you acknowledged at the start). Could have done with slimming the slides down to summary points.
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Prior knowledge assumed	Prior knowledge assumed	N/A, but moved comment from question 7
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	Blank/None	Blank/None	
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Hand layup exercise	Practical	Some of the lay-up practical exercise was too long and not required
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	Blank/None	Blank/None	
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	Too much content	Too much content	Lots of powerpoint slides
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Too much content	Too much content	Presentations seemed to go on for a while and could have benefitted from something to break them up more. Videos, more practical etc
PC1	Y	Mix	20	30	Production Costing	Too much content	Too much content	There was a lot to take in. Not sure If will ever have to cost a whole factory but who knows!
PC2	N	Computer	0	Too many	Production Costing	Blank/None	Blank/None	
PC3	Y	M&C	Blank	10	Production Costing	Blank/None	Blank/None	
PC4	Y	Computer	8	8	Production Costing	More examples needed	Insufficient examples	Can do with more examples!!
PC5	Y	M&C	15	24	Production Costing	Design for manufacture	Lecture section	DFM...

PC6	Bla nk	M&C	Blank	Blank	Production Costing	Virtual composites company spreadsheet	Practical	Spreadsheet was a bit dry! Could simplify and create quick cost analysis from scratch on spreadsheet


Least favourite parts of course- categories
10
9
8
7
6
5
4
3
2
1
0
Blank/None
Example/case study
Insufficient examples
Lecture section
Practical
Prior knowledge assumed
Slides too verbose
Too much content
Tolerancing, Variability and Defects
Production Costing
An Introduction to the History and Manufacture of Composite Materials



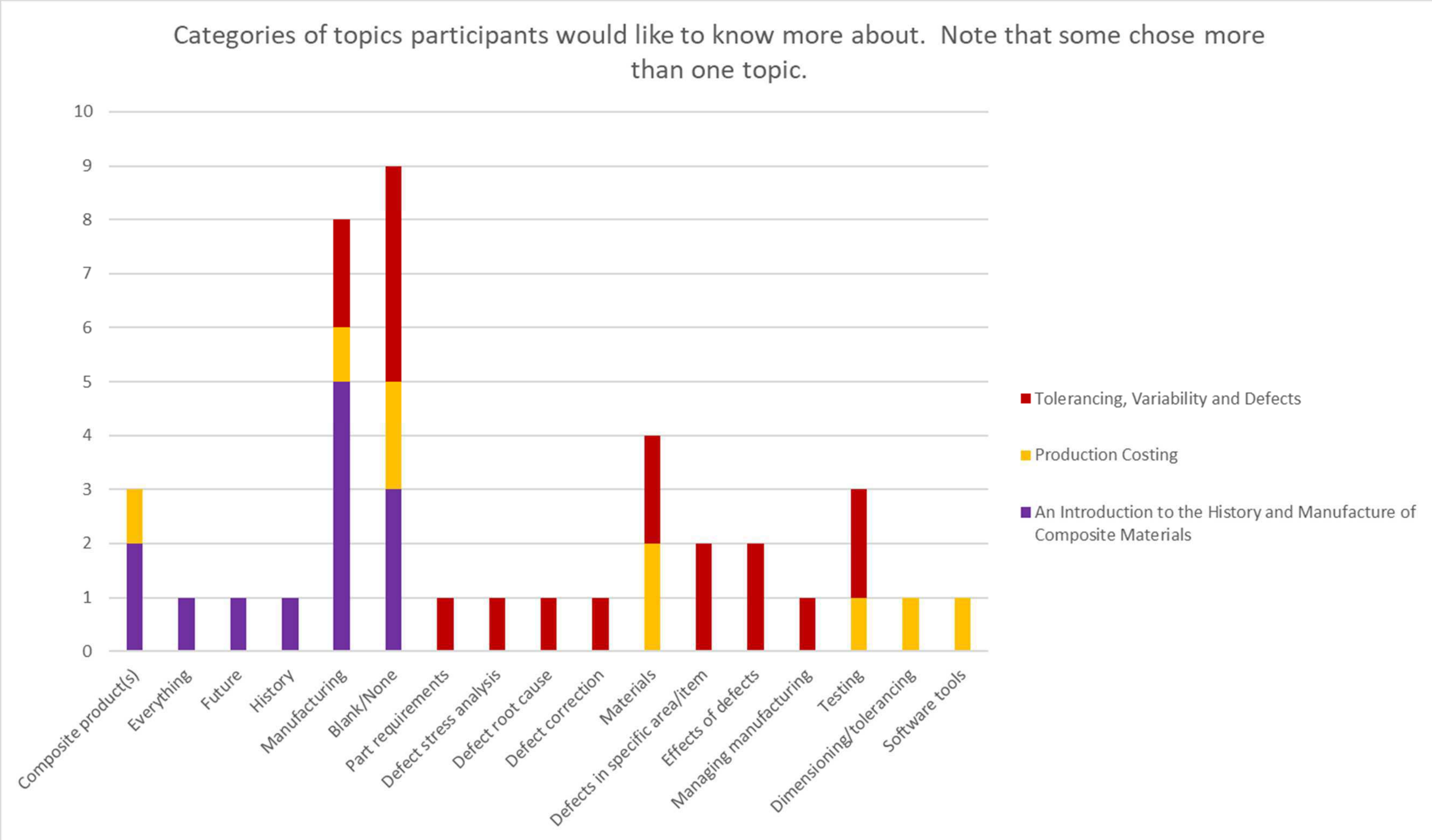
Least favourite parts of course- detail
12
10
8
6
4
2
0
Blank/None
Design for manufacture
Effects of defects
Engineering drawing exercise
Hand layup exercise
More examples needed
Prior knowledge assumed
Process comparison
Repair and concessions
Slides too verbose
Too much content
Virtual composites company spreadsheet
Tolerancing, Variability and Defects
Production Costing
An Introduction to the History and Manufacture of Composite Materials

Question 6

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Topics(s) they would like to know more about	Category	Full quote
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Manufacturing aircraft	Manufacturing	Manufacturing aircraft
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Aeroplanes	Composite product(s)	aeroplanes
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	History	History	history
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Blank	Blank/None	
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Everything	Everything	Everything. I am going to go over the material to understand things more.
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Resin infusion	Manufacturing	Resin infusion
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	None	Blank/None	N/A
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Blank	Blank/None	
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Mass production	Manufacturing	Mass production -
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Future trends and possibilities	Future	future trends/possibilities
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Resin Transfer Moulding	Manufacturing	RTM
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Non-aerospace/automotive applications	Composite product(s)	Applications outside aerospace/automotive industries
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Mould design	Manufacturing	Mold design
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	Accounting for defects in requirements	Part requirements	How defects can be taken into account in the

TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	Stress analysis of defects	Defect stress analysis	composite engineering requirements and how can be analysed from a stress point of view
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	Investigating defect root cause	Defect root cause	Defect root cause, investigation
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	Defect correction	Defect correction	and corrections
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Materials other than prepreg	Materials	More types of material - mostly pre-preg covered in this course.
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Manufacturing	Manufacturing	More on manufacturing of composites.
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	Manufacturing	Manufacturing	General manufacturing processes
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Defects in assemblies/joints	Defects in specific area/item	Defects in assemblies/joints if possible.
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Defects/variability in CFRP tools	Defects in specific area/item	Defects & variability in CFRP tools
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Experimental data on effects of defects	Effects of defects	Further experimental data on effect of each defect. + clearer
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Inspections and working procedures	Managing manufacturing	Development of working/inspection procedures
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Blank	Blank/None	
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Materials variability and specifications, OOA	Materials	With respect to materials variability & materials specifications. Content was mainly with respect to autoclave tech. How does out of autoclave tech differ? Or is it very similar?
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	Testing	Testing	Testing

TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Defect knock down on mechanical properties	Effects of defects	Linking defects to knock down in mechanical properties.
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	Non-destructive testing	Testing	New NDT developments
TVD12	Y	M&C	0.333 3	2	Tolerancing, Variability and Defects	Blank	Blank/None	
TVD13	N	Comp uter	0	18	Tolerancing, Variability and Defects	Blank	Blank/None	
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Blank	Blank/None	
PC1	Y	Mix	20	30	Production Costing	Costings of more processes	Manufacturing	I am going to look into more processes
PC1	Y	Mix	20	30	Production Costing	Costings of more materials	Materials	& materials and relevant costings
PC2	N	Comp uter	0	Too many	Production Costing	Composite materials	Materials	Composite materials
PC2	N	Comp uter	0	Too many	Production Costing	Applications for composite materials	Composite product(s)	& application
PC3	Y	M&C	Blank	10	Production Costing	Blank	Blank/None	
PC4	Y	Comp uter	8	8	Production Costing	Non-destructive testing	Testing	NDT
PC4	Y	Comp uter	8	8	Production Costing	Geometric dimensioning and tolerancing	Dimensioning/toleranci ng	G&DT
PC5	Y	M&C	15	24	Production Costing	Blank	Blank/None	
PC6	Blank	M&C	Blank	Blank	Production Costing	Open source cost modelling tools	Software tools	Open source costing model tools?



Categories of topics participants would like to know more about. Note that some chose more than one topic.
10
9
8
7
6
5
4
3
2
1
0
Composite product(s)
Everything
Future
History
Manufacturing
Blank/None
Part requirements
Defect stress analysis
Defect root cause
Defect correction
Materials
Defects in specific area/item
Effects of defects
Managing manufacturing
Testing
Dimensioning/tolerancing
Software tools
Tolerancing, Variability and Defects
Production Costing
An Introduction to the History and Manufacture of Composite Materials

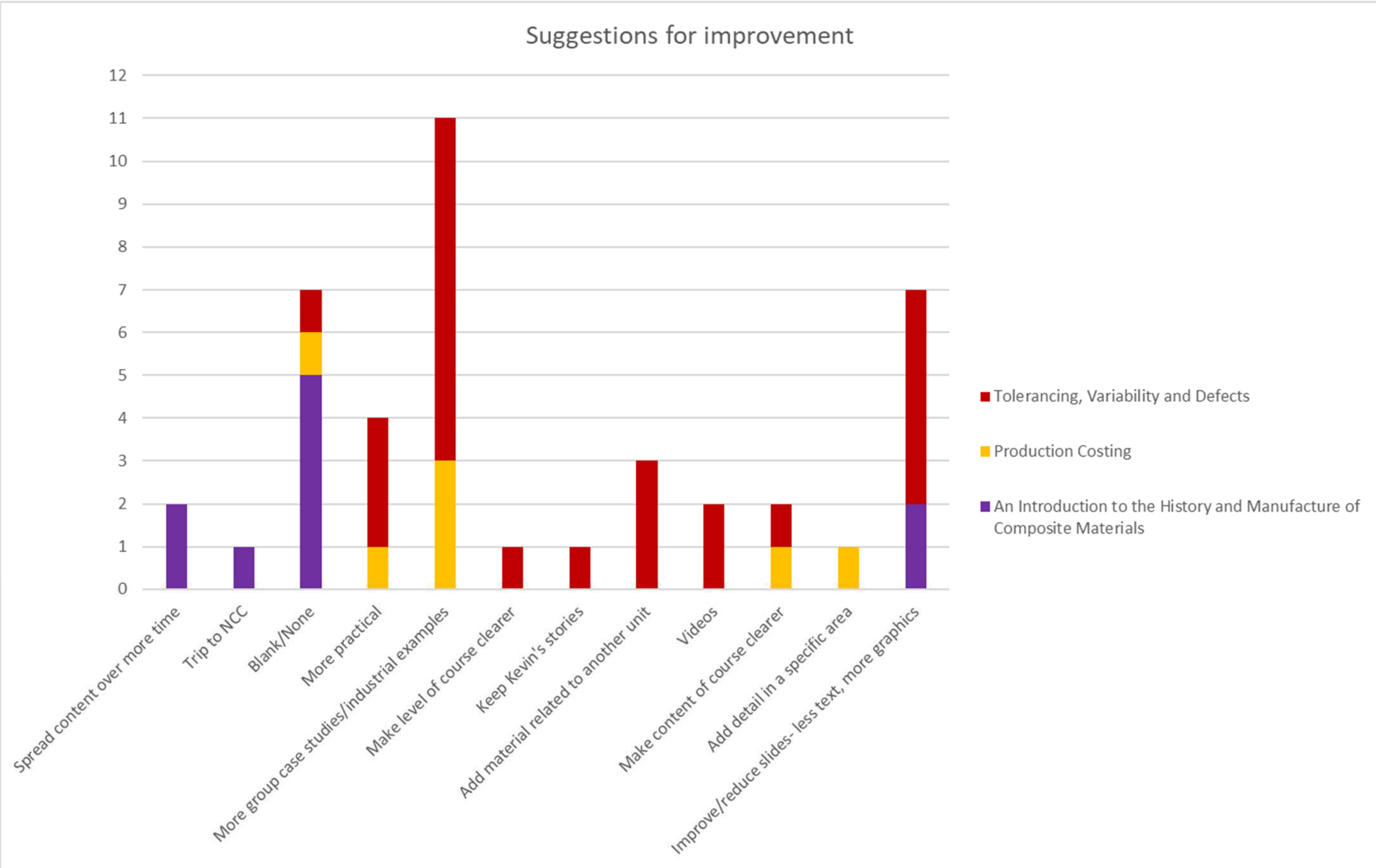
Question 7

Person	Compj ob?	Job type	Yrs comp	Yrs eng	Course	Suggestions for improvement	Full quote
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Blank/None	None
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Blank/None	
UWE3	Stude nt	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	Spread content over more time	More time- too much content. Spreading the talk over a longer period of time to give more time to understand and ask questions
UWE4	N	Meeti ngs	Blank	13	An Introduction to the History and Manufacture of Composite Materials	Trip to NCC	Could be based around a trip to NCC?
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Spread content over more time	Breakdown content and split out over longer period of time
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	Blank/None	
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	Blank/None	
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Blank/None	
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	Improve/reduce slides- less text, more graphics	Make easier to understand slides, less text, more figures and graphic examples- less information on slides
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	Improve/reduce slides- less text, more graphics	Lots of words on slides- not all used

TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	More practical		Add more practical and ??? Examples
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	More group case studies/industrial examples		More group problem solving to discuss real life issues as these help the understanding of the presented material
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Improve/reduce slides- less text, more graphics		More images of defects in slides to break up words
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	More group case studies/industrial examples		+ more case studies.
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	Make level of course clearer		Unclear on level pitched at. Presumed some prior knowledge.
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	More group case studies/industrial examples		More engagement through the slides. "table exercises" would probably help
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	More group case studies/industrial examples		The more exercises the better,
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Improve/reduce slides- less text, more graphics		a few more pictures/diagrams too.
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	Keep Kevin's stories		Kevin's industrial expertise is invaluable. If the presenter just followed the slides it could be boring. Kevin's anecdoetes & tips/gems are key to this
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	Add material related to another unit	NDT	Add in information on how to detect + measure defects (NDT, microscopy, CT, metrology techniques) -> Advantages + limitations. Do this through slides + practical exercise (NCC would probably be able to support exercise).
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	More group case studies/industrial examples		More practical examples
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	Improve/reduce slides- less text, more graphics		less slides
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Add material related to another unit	Stress analysis (classical)	Calculations, tolerance stacks, hand calcs on stress from defects.
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	More group case studies/industrial examples		Perhaps add some worked numerical examples of problems we may see that we can apply in our industry roles.
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	Improve/reduce slides- less text, more graphics		From Q5

TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	Add material related to another unit	Characteristics of fabric reinforcement, Polymer melt viscosity and chemorheology	Some content requires previous knowledge. Perhaps inclusion of slides detailing definitions of subjects like drape, permeability, rheology etc
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	Improve/reduce slides- less text, more graphics		Less text on slides
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	More group case studies/industrial examples		More discussion on design drawings. Maybe starting with basics. Some examples of good ones. Not just jumping straight to the terribles one.
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	Blank/None		
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	More practical		Break up the powerpoint slides with other things.. Maybe more practical work or videos or more student interaction
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	Videos		
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	More group case studies/industrial examples		
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Make content of course clearer		The course seemed to be mainly based on autoclave and aerospace. This, although not too much of an issue, was not made clear.
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	Videos		From Q5
TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	More practical		From Q5
PC1	Y	Mix	20	30	Production Costing	More group case studies/industrial examples		We could have gone through a worked example with the cost tool- but will have a go I
PC2	N	Computer	0	Too many	Production Costing	More practical		Some composite hard exhibits
PC3	Y	M&C	Blank	10	Production Costing	Blank/None		
PC4	Y	Computer	8	8	Production Costing	Make content of course clearer		Clear course objectives & evaluate
PC4	Y	Computer	8	8	Production Costing	More group case studies/industrial examples		From Q5

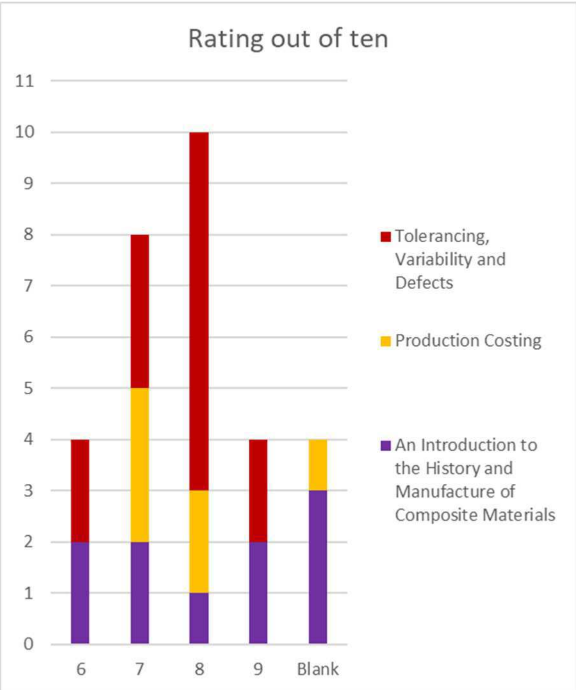
PC5	Y	M&C	15	24	Production Costing	Add detail in a specific area	Probably more emphasis on RC &NRC split, impacts of processing on tooling & NRCs
PC6	Blank	M&C	Blank	Blank	Production Costing	More group case studies/industrial examples	From Q5



Question 8

Person	Compjob?	Job type	Yrs comp	Yrs eng	Course	Rating out of 10
UWE1	N	Blank	0	6	An Introduction to the History and Manufacture of Composite Materials	Blank
UWE2	Blank	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	9
UWE3	Student	Blank	Blank	Blank	An Introduction to the History and Manufacture of Composite Materials	7
UWE4	N	Meetings	Blank	13	An Introduction to the History and Manufacture of Composite Materials	7
UWE5	Y	Mix	Blank	8	An Introduction to the History and Manufacture of Composite Materials	Blank
UWE6	N	Mix	0	8	An Introduction to the History and Manufacture of Composite Materials	6
UWE7	N	Mix	1.5	17	An Introduction to the History and Manufacture of Composite Materials	8
UWE8	N	M&C	0	14	An Introduction to the History and Manufacture of Composite Materials	Blank
UWE9	N	M&C	0	7	An Introduction to the History and Manufacture of Composite Materials	6
UWE10	N	Mix	0	5	An Introduction to the History and Manufacture of Composite Materials	9
TVD1	Y	Computer	5	12	Tolerancing, Variability and Defects	8
TVD2	Y	Computer	5	8	Tolerancing, Variability and Defects	8
TVD3	Y	Computer	Blank	2	Tolerancing, Variability and Defects	7
TVD4	Y	M&C	1	10	Tolerancing, Variability and Defects	8
TVD5	Y	Mix	1.5	8	Tolerancing, Variability and Defects	8
TVD6	Y	Mix	4	4	Tolerancing, Variability and Defects	6
TVD7	Y	Mix	4	11	Tolerancing, Variability and Defects	8
TVD8	Y	M&C	1	9	Tolerancing, Variability and Defects	7
TVD9	Y	M&C	3	12	Tolerancing, Variability and Defects	9
TVD10	Y	Computer	0.5	4	Tolerancing, Variability and Defects	8
TVD11	Y	Mix	8	12	Tolerancing, Variability and Defects	8
TVD12	Y	M&C	0.3333	2	Tolerancing, Variability and Defects	9
TVD13	N	Computer	0	18	Tolerancing, Variability and Defects	6

TVD14	Y	M&C	2	7	Tolerancing, Variability and Defects	7
PC1	Y	Mix	20	30	Production Costing	8
PC2	N	Computer	0	Too many	Production Costing	8
PC3	Y	M&C	Blank	10	Production Costing	Blank
PC4	Y	Computer	8	8	Production Costing	7
PC5	Y	M&C	15	24	Production Costing	7
PC6	Blank	M&C	Blank	Blank	Production Costing	7



Appendix 6- Original HEFCE bid

Catalyst Fund: Closing the skills gap and supporting the Industrial Strategy through curriculum development

HEFCE business case template

Project information			
Lead institution	University of Bristol		
Project title	Composites Curriculum Development		
Project start date	01/01/2018		
Project end date	01/01/2019		
Contact person for the proposal			
Title and full name	Professor Kevin Potter		
Position	Professor in Composites Manufacture		
Address for correspondence	Department of Aerospace Engineering, Office 0.54a, Queen's Building, University Walk, BS8 1TR		
Phone	+44 (0) 117 33 15277		
Email	k.potter@bristol.ac.uk		
Partners			
Other institutions involved	University of Plymouth		
Other key partners and investors	National Composites Centre		
Funding and investment			
Total Catalyst Fund request		£200,000	
Total funding from other sources		£100,000	
Breakdown of funding from other sources 1.0 FTE Staff resource			
Revenue	**£300,000**	Capital	**£**
Total project cost	**£300,000**		
Compliance with state aid and other relevant legislation			
In your opinion, are state aid issues applicable to this project?		**No**	

Project description

The project will collaborate with the industrial partners of the National Composites Centre (a High Value Manufacturing Catapult hosted by the University of Bristol), to fund the curriculum design and development of innovative master's level work-based learning in composites design and manufacturing. Using the capability and infrastructure of the National Composites Centre as the underpinning technology knowledge base, such curriculum will be tailored to demonstrated industrial need and co-designed with industry to be primarily accessible to second cycle learners from a range of composite disciplines. This well-structured and comprehensive portfolio of learning material will catalyse the creation of a sustainable training activity to up and re-skill existing and future workforce, and will potentially have significant impact in closing the skills gap. Professional accreditation of non-credit bearing courses will be sought from the Institute of Materials, Minerals and Mining (IOM3) and the Institution of Mechanical Engineers (IMechE).

This project is aligned with the priorities of the Government's green paper, 'Building Our Industrial Strategy', in particular skills development (Pillar 2), cultivating world leading sectors (Pillar 8), and driving growth (Pillar 9).

Rationale for funding

Availability of a workforce with appropriate knowledge and skills plays a vital role in the success of UK advanced manufacturers to compete globally, with a lack of access to a suitably skilled workforce often stated as one of the top 3 barriers to growth [EEF]. In a developing sector such as composites, which is forecast to experience growth rates of 15% per year through to 2020 [UK Composites Strategy 2016], the challenge faced is particularly difficult and more pronounced.

The 2016 UK Composites Strategy, compiled by the Composites Leadership Forum, an industry-led trade body, saw a serious 'potential risk of decline in market value by 2030 if technology and supply chain is not supported' – owing to the poor provision of skilled staff. The document further states that "the current pool of people is small and as demand is increasing rapidly this has already become a major inhibitor to growth".

At present, many composite-using companies have neither the capacity nor capability to provide in-house training programmes to up or re-skill their workforce. Instead, they look to the higher education (HE) sector to provide skills gaps solutions in the delivery of continuing professional development (CPD) short courses (credit and non-credit bearing). However, an endemic lack of industry input into the curriculum design and mode of delivery of HE courses indicates a missing mechanism, leading to low levels of engagement and enthusiasm. Furthermore, the process of selection can be difficult since no official database currently exists to facilitate the distribution of information of current courses incl. providers, content, learning outcomes, depth of content etc. If we are to close the skills gap in composites engineering through the development of innovative curricula, and ensure that we are providing a real service to industry with tangible benefits in design and manufacture with composites, then we must address the three main market failures:

1. Lack of industry input into curriculum design
2. Lack of integrated marketing and information of current HE provisions in learning
3. Lack of application-based learning material in composites engineering tailored to the needs of industry, and which exploits the unique and world-leading composites technology and manufacturing capabilities of High Value Manufacturing Catapults.

To help address this market failure, there is a strong case for the University of Bristol and the University of Plymouth to work jointly with the industrial partners of the National Composites Centre to co-design and co-develop a portfolio of innovative topic-based learning materials.

The Bristol Composites Institute (ACCIS) is a world-leading institute for composites research and education, combining blue-sky research with strong industrial links for exploitation and knowledge transfer. These activities are underpinned by its strong provision in postgraduate learning paths for advanced manufacturing subjects, and its strong links with other leading HE institutions and industry in composites manufacturing - through the EPSRC Future Composites Manufacturing Research Hub and the IOM3 British Composites Society.

The Materials and Structures (MAST)/Composites Engineering is a leading composites R&D facility at the University of Plymouth with many years' experience in running short courses and workshops in composites design and manufacture, attracting over 2500 delegates industrial delegates. It is the only UK HE institution to offer Engineering Council accredited undergraduate degrees specialising in composites. Professor Summerscales was the inaugural Chair of the British Composites Society (BCS) Education, Professional Development and Recognition (EPDAR) sub-committee from 2009-2014. Dr Jasper Graham-Jones is University of Plymouth School of Engineering Academic Liaison Officer for eleven partner colleges bounded by Bristol, Falmouth, Jersey and Yeovil. The HEFCE proposal presents a timely opportunity to use Plymouth's expertise and provision as a template for a defined minimum national composites curriculum. Professor John Summerscales has also been involved in discussions with the named co-applicants over a number of years. This project will assist in strengthening links with both NCC and the University of Bristol.

The National Composites Centre (NCC) is a High Value Manufacturing Catapult (HVMC) which provides industrial scale Research and Technology Development facilities to meet the needs of all sectors wishing to capitalise on the high-strength, low weight, corrosion-resistant qualities of composite materials. NCC works with many established users of advanced fibre composites in the aerospace, automotive, rail and other industries, and is also supported by a number of materials, equipment supplier and software houses. The NCC's status as a world leading centre of excellence in composites, and as one of the largest UK employers of composite skilled staff, gives the project further credibility - providing the necessary support and resources to help realise the goals of the project.

The funding sought here will pay for the time of academic staff from Bristol and Plymouth to work with industry partners at the NCC to quantify curriculum requirements, identify gaps, and develop learning content.

Fit with organisational strategy

The University of Bristol has a strategic commitment to develop postgraduate research training relationships with HE institutions and industry partners. The Bristol Composites Institute (ACCIS) is home to both the EPSRC Centre for Doctoral Training (PhD) and the Industrial Doctorate Centre in Composites Manufacturing (EngD level), supporting a large number of scientists and engineers via an innovative programme of training. Under the EngD programme, research engineers conduct PhD-equivalent research and undertake taught technical courses whilst working closely with an industrial sponsor at the NCC. Previous and current projects have involved AgustaWestland, Airbus, dstl, GE Aviation, Haydale, RNLI, Rolls-Royce, Jaguar Land Rover and Vestas. The significant investment and strong industrial involvement illustrates the scale of the challenges ahead and highlights the importance and expected benefits in seeking to rebalance the economy towards high value manufacturing using composite materials [WECA]. A major highlight of the taught course component is the Design, Build and Test project, which provides hands-on experience and allow students to apply their attained understanding and analysis of composites to real world industrial problems. This pedagogical model of application-based learning (involving a suite of masters' level taught units) will serve as a template and model for the HEFCE project.

The University of Bristol also has a strategic commitment to review, reshape and expand our portfolio of taught postgraduate masters' and continuing professional development programmes to ensure that they are fit for purpose in the national and international marketplace in terms of their content, structure and modes of delivery.

In 2014, Phase 2 of the National Composites Centre was built, doubling the size of the centre to enhance its ability to include skills, training and further development opportunities for the UK Composites Industry. However, this investment needs to be complemented more widely by a significant increase in the availability of work-based learning content in the form of contextual CPD and short course learning, as proposed in the HEFCE bid.

The University of Plymouth is one of the very few HE institutions to offer dedicated composite courses at degree level. Since 1987, Plymouth has provided CEng/IEng accredited degree pathways to over 500 graduates, many of whom have risen to important roles in the sector, and has provided a strong provision of accredited short courses to industrial delegates. Plymouth will bring their respective insight and expertise to the HEFCE proposal in the area of curriculum mapping and design, and the associated access of learning resources and other sector data held within systems at Plymouth. The HEFCE activity also complements Plymouth's School of Engineering Strategy which expects to see a new Engineering Building for teaching, research and industrial collaboration in the near future with increase space allocated to composites.

The University of Bristol and the National Composites Centre are also official delivery partners of the Composites Leadership Forum (CLF), an industry-led body working to coordinate and connect the activities of composite-using companies with skills and training. The 2016 UK Composites Strategy identified an urgent need to develop not only new people with the right skills, but re-skilling and up-skilling those already in work with the necessary composite skills and knowledge. The recommendations made to meet this forecast demand is beyond the scope of NCC Phase 2 and what is currently being provided in the UK, hence the urgent need for this HEFCE proposal.

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Wider benefits

A key benefit of this project is the use of education / teaching material to trigger and facilitate wider adoption and usage of composites. The National Composites Centre has received over £70m in technology investment, the next step is to embed a 'knowledge transfer' culture in the education/training domain by providing 'end-to-end' learning paths for employees. The transfer, wider adoption and engagement with the practical and process aspects of composites are key to de-risking the technology for many employers.

By working with industrial partners of NCC to produce the skilled workforce of the future, through learning and knowledge transfer, helps to anchor and secure market share, growth and jobs in the UK. This will benefit the wider public – through lighter and more fuel efficient aero-engines or cars, safer and more durable structures, or the engineering of more sustainable materials.

This proposal will help support the National Composites Centre and its Tier 1,2 members who at present do not have the resources or critical mass of learning expertise to develop a portfolio of learning objects and material of this scale alone. This project will develop a unique partnership between industry and HEIs to ensure that the curriculum is fit for purpose and that the project will help provide an impact beyond participating institutions and will provide benefits to the local and wider economy. The database of current HE provisions will also direct industrial clients more smoothly towards the most appropriate training course for his/her particular training needs, resulting in healthy competition between providers.

This proposal is also predicated on key Government and HEFCE priorities related to the need for HE to be a key driver in supporting and enhancing local economic activity through producing HE learners equipped with the right skills and knowledge for useful and productive careers, and improved knowledge exchange with employers.

Finally, the wider industrial education and training landscape requires the provision of flexible application-based CPD material rather than conventional full-time or part-time HE programme. This will bring huge benefits to employers as it will allow staff to develop specific capabilities and knowledge as and when required rather than studying for a complete qualification. Individuals can also seek recognised qualifications providing long term professional development and employment security.

Dissemination and review

The project will adopt a range of strategies designed to achieve sustainable impact beyond the 12-month lifetime of the project. Engagement and dissemination during the project will take place via (but not limited to) the following activities:

- Publication and dissemination of outcomes from curriculum mapping exercise to industrial partners and HEIs (learner numbers and course uptake).
- Regular communication of project activities and findings to key beneficiaries (West of England Combined Authority), seeking guidance and feedback where appropriate.
- An on-going communication strategy including the use of quarterly Newsletters and a project website.
- Use the NCC to promote dissemination of the resulting portfolio of training material to a wide range of industrial stakeholders from different sectors via seminars and showcase events

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Inputs, outputs and outcomes

Using the table below detail the key inputs, activities, outputs and outcomes for the project. Include specific targets which are clearly aligned with the HEFCE funding period. Please confirm when any baseline measures will be available.

This table will be used to draft the success criteria and measures for project monitoring purposes, should the bid be approved for funding.

Input	Activity	Output	How financed or resourced	Outcomes (short-, medium- and long-term)	Measurable impacts
0.25 FTE (UoB) 0.25 FTE (HEFCE-UoB) 0.0625 FTE (HEFCE-Ply.)	Curriculum mapping exercise: identify the composites learning provision from leading UK HE providers and benchmark this against our international comparators.	Curriculum map and database will provide an accurate status of HE capability and capacity for composites learning by subject area incl. CPD/short courses.	HEFCE & University of Bristol	Establish formal links between the providers and end-users, and to facilitate the distribution of information of current HE provisions.	Quantify provision, current demand, participation rates and capacity of undergraduate, postgraduate, and CPD/short courses in Composites Engineering.
0.08 FTE (UoB) 0.08 FTE (HEFCE-UoB) 0.0208 FTE (HEFCE-Ply.)	Demand model and gap analysis: Curriculum framework design and specification through a structured consultation exercise with industry and academia. Priority of response to gaps in current HE provisions	A learning / curriculum matrix of key topics informed by industry and academia. Requirements for new materials and resource allocation.	HEFCE & University of Bristol	Academic and industrial engagement in curriculum design, teaching and learning. Guarantee that curriculum output is fit for purpose with industrial partners. Clarity on learning development needs and ensure fit for purpose curriculum.	Key metrics: increase in uptake; participating in meetings, events and workshops; identify relevant case studies; providing learners and HE providers with access to equipment and resources; and sharing practice. Increase in enrolment of learners from industry on such courses.

0.42 FTE (UoB) 0.42 FTE (HEFCE-UoB) 0.1042 FTE (HEFCE-Ply.)	Develop a set of appropriate low-cost learning objects and resources – including texts, course notes presentation, practical sessions and assessment criteria incl. worked through examples and industrial case studies.	Produce a portfolio of flexible topic-based learning material,	HEFCE & University of Bristol	Make the content and objects available to National Composites Centre.	Increase in industry personnel undertaking CPD training or re-skilling and / or up-skilling programmes.	
0.17 FTE (UoB) 0.17 FTE (HEFCE-UoB) 0.0417 FTE (HEFCE-Ply.)	Dedicate resources to pilot curriculum at National Composites Centre	CPD/Short course	HEFCE & University of Bristol	Teaching of HE staffs in work-based environment. Assess learning approach in terms of mode of delivery, depth of content and workplace relevance.	Learning experiences and outcomes relating to teaching and learning developments and innovations: e.g. course evaluation feedback; learner and employer satisfaction.	
0.08 FTE (UoB) 0.08 FTE (HEFCE-UoB) 0.0208 FTE (HEFCE-Ply.)	Lessons learnt and make content available to industrial partners of NCC	Catalogue of learning objects and case studies made available to industrial partners of NCC.	HEFCE & University of Bristol	Resolve IP ownership at publication and in future. Disseminate outcomes of project to relevant stakeholders.	Key metrics: license structure with HE and NCC. Further up-take of CPD/short courses from baseline measures.	

Total project costs and funding per year

Table 1: Revenue funding	**Principal use of funds**	**Academic year 2017-18**	**Academic year 2018-19**	*[add other years for full length of project]*	**Total £**
Institution's own funds	1.0 FTE to support curriculum development activities	£58,000	£42,000		£100,000
HEFCE Catalyst Fund	1.20 FTE (Bristol) and 0.25 FTE (Plymouth) incl travel and co-development costs	£117,000	£83,000		£200,000
HEFCE other grant (*give detail*)					
Other 1 (*name source*)					
Other 2 (*name source*)					
Total		£175,000	£125,000		£300,000

Table 2: Capital funding	**Principal use of funds**	**Academic year 20XX-XX**	**Academic year 20XX-XX**	*[add other years for full length of project]*	**Total £**
Institution's own funds					
HEFCE other grant (*give detail*)					
Other 1 (*name source*)					
Other 2 (*name source*)					
Total					

Table 3: Total funding	Academic year 2017-18	Academic year 2018-19	*[add other years for full length of project]*	Total £
Institution's own funds	£58,000	£42,000		£100,000
HEFCE Catalyst Fund	£117,000	£83,000		£200,00
HEFCE other grant (*give detail*)				
Total	£175,000	£125,000		£300,000

Is the institution borrowing to fund this proposal? **No.**

Leverage

Please complete the table below advising of any leverage that Catalyst Funding would secure. Where possible, provide evidence of committed funds, and detail any specific conditions of these grants.

Funding source	Amount	Status*	Notes
National Composites Centre, High Value Manufacturing Catapult	£500k	Secured	NCC Composites Transition Programme – April 2018. Enquiries already received for programmes similar in nature to 'conversion course'. April 2018 programme will inform HEFCE Catalyst work.

*Options for status column: *secured*, *secured in principle*, *secured with conditions*, *pending outcome*, *identified but not approached.*

Value for money

Describe how the project represents excellent value for money – this should be against the outputs and targets to justify the costs involved and overall funding request to HEFCE.
Describe how the costs relate to the outputs of the project, and describe how the mix of public, private and institutional funds is proportionate.

We are seeking here a one-off funding of an intense 12-month period of curriculum horizon scanning, course design and development that will lead to a flexible portfolio of learning material that will be initially piloted to a dedicated cohort of learners at the NCC in 2018. Once assured and accredited, this content will then be made accessible to the industrial partners of the NCC (nearly 50 tier 1,2 members) to be used for a variety of levels and audiences. **The NCC alone** (not including industrial partners) is expected to recruit over 250 research engineers over the next few years so we can expect well in excess of 100 annually once the content is fully developed and accredited. Hence this project has a target of some 1,000 learners over a 5-year period. In terms of cost per head, this represents good value for money. Learner and delegate numbers will be monitored and reported by the project. The additional funding from the University of Bristol to support this HEFCE project, presents a rare opportunity to begin to address the demand for workplace curriculum in composites engineering to secure market growth and jobs, which is directly aligned with the UK Industrial Strategy.

There are several ways in which value for money can also be achieved:

- The combined capacity, expertise and academic and industrial networks of the three partners will considerably reduce consultation, dissemination and networking costs.
- Utilising the expertise and national and local employer links of over 50 composite-using companies via the NCC.
- Controlling costs by using salary rates related to the higher education sector to buy-out staff time for curriculum development activities.

Sustainability: Financial

How will the overall project or its key activities be sustained beyond the HEFCE funding period?
Describe the cost base needed to sustain the project beyond any HEFCE funding period, the other forms of investment and income that will be provided in the longer term, and how they will be secured.
What efficiencies will be generated by the project?

The funding being sought here provides for the modest number of FTEs that need to be dedicated in initial curriculum mapping, design, development, and pilot delivery. After the course material developed by this funding is made available to the NCC and its industrial partners, the University of Bristol and NCC would take on the costs of ongoing updates and revisions, as routine business funded ultimately by regular income streams, e.g. from Catapult funding. There is no immediate plan to monetise the content created by this project, certainly not until content has been professionally accredited by the IMechE and IOM3, although it could in principle be used for delivery of bespoke courses to industry as conversion courses or re-skilling purposes.

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Project risks

Identify the top five risks to this project, how they will be mitigated and their probability versus their impact.

Depending on the information provided in this section, we may also request a full risk register to support our assessment process.

Risk	Mitigation	Probability and impact
Lack of wide agreement on overall curriculum and content	Mitigated by early establishment of academic and industrial oversight. Bristol and Plymouth are both members of the Bristol Composites Society (BCS) board meetings. Bristol is also a member of the EPSRC Future Composites Manufacturing Hub.	Low probability – High impact
Identifying and unlocking the people with the right skills to deliver the required academic/teaching materials from their days jobs at the right time, and manage development to time and cost	Take early steps to identify and secure the release of key individuals for the necessary timescales.	Without HEFCE funds – high probability and high impact.
Attract buy-in and dissemination of products with industry	Mitigated by early promotion of activities at industrial seminars and meeting.	Low probability of poor engagement from NCC and Tier members. High impact
Investigate and resolve IP ownership at publication and in future.	Establish license structure with HE and Catapult partners.	Medium probability and high impact if HE and Catapult partners fail to agree licensing structure.
Course content becomes out of date, obsolete or requires continual updating.	Although course content will require updates over time to reflect emerging and developing technology, the core elements of the course will have reached a level of technological maturity to satisfy the next 10-20 years. Academic and industrial partners are world-leading professionals – at the forefront of current and emerging technology.	High probability that some elements of the course will need updating and refining over time. Low impact if resources continue to be dedicated to maintaining and developing course material.

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Accountability and governance *Describe the governance and management structures and arrangements for the project, including the accountable person (the project manager) for delivery. State who is ultimately responsible for project delivery and success –for instance, the Pro Vice-Chancellor or Vice-Chancellor.* The principal investigator of this project is Professor Kevin Potter. The Head of School of Civil, Aerospace and Mechanical Engineering, Professor Ian Bond, at the University of Bristol is ultimately responsible for project delivery and success. The project manager responsible for delivery is Dr Galal Mohamed, Senior Research Associate at the University of Bristol. Under the umbrella of the Composites Leadership Forum, organisations such as Composites UK, the National Composites Centre, the British Composites Society, and the EPSRC Future Composites Manufacturing Research Hub, will provide quality assurance and accreditation oversight of course development activities on a quarter-yearly basis.
Impact assessment: Equality and diversity *Detail the processes that have been or will be undertaken to review the impact of this project relating to equality and diversity* The project is designed to deliver benefits and positive outcomes to all project stakeholders, particularly to all types of learners irrespective of their different characteristics and backgrounds. The University of Bristol and the University of Plymouth all have significant experience and expertise in addressing the particular needs of the different individuals and groups in the nine protected areas covered by the Equality Act (2010). In particular, they are focused on how their policies, practices and decisions impact on different individuals and groups when thinking about their focus on improving the quality of education, improving learner choice, and enhancing the learner experience. We would therefore expect the project to have a positive impact on equality and diversity issues if the project outcomes are achieved, through supporting a step change in access to high-quality learning resources and short courses for the full range of potential learners across all protected areas. Both HE institutions recognised that the HE sector serves, and draws, on the talents and skills of a diverse population. Furthermore, both HE institutions hold a bronze Athena Swan aware for recognising commitment to advancing women's careers in STEMM academia.

Confirmation of approval for proposal

Proposals will only be considered if they have appropriate senior university or college support. We cannot accept bids from individuals.
Attach a supporting statement or letter from the head of the lead institution and other project partners as appropriate.
Attach a supporting statement or letter from Director of Finance at the lead institution.
NB: All letters should ideally be submitted as one document.

In addition to the supporting statements/letters specified above, please also note the attached additional letters of support:

- Letters of support from National Composites Centre and Composites UK

Key milestones

Key milestones based on the template below should be completed and submitted with the business case. We require a summary of the activities involved in the project, the associated key risks and how these will be mitigated, and how the milestones fit with the project's success criteria, impacts and outcomes.

Target	Key milestone	Key risks	Actions to mitigate risk	Completion date	Outcome
Target 1	Conclusion of Curriculum mapping exercise	Poor engagement and buy-in from partner HEIs	Attract buy-in of curriculum mapping exercise through existing network channels via EPSRC Future Composites Manufacturing Research Hub and the British Composites Society	March 2018	Results will be used to inform availability and level of learning in core composite areas of design, stress, materials and manufacturing.
Target 2	Demand and gap analysis through structured consultation with industry and HEIs	Lack of wide agreement on overall curriculum and content	Mitigated by early establishment of academic and industrial oversight. NCC will act as a conduit to engage industry buy-in and engagement.	April 2018	Verification and validation that curriculum is fit for purpose and prioritise response to gaps appropriately.
Target 3	Development of contextual learning objects and materials incl. NCC based case studies	Identifying and unlocking the people with the right skills to deliver the required academic/teaching materials from their days jobs at the right time, and manage development to time and cost	Take early steps to identify and secure the release of key individuals for the necessary timescales.	October 2018	A strong portfolio of work-based learning material that can be initially piloted at the NCC through their workforce development schemes.

Target 4	Pilot curriculum at National Composites Centre	Clash of schedules due to University teaching timetable and NCC recruitment activities.	Take early steps to engage with UoB and NCC to schedule block delivery of content and ensure resources are available.	November-December 2018	Lessons learnt and feedback to improve learner experience before making content more widely available.

Appendix 7- Monitoring report July 2018

Catalyst Fund: Closing the skills gap and supporting the Industrial Strategy through curriculum development

Interim monitoring report

HE Provider	University of Bristol
Project title	Composites Curriculum Development
Project code	N12
Contact name	Kevin Potter
Email	aekdp@bristol.ac.uk
Tel No.	0117 331 5277
Date report due	31 July 2018
Date report submitted	
Frequency for reports to be submitted to OfS:	The project will be monitored formally at two points: • **31 July 2018 - Interim monitoring report (incorporating all activity to the end of March 2018)** • **28 February 2019 - Final report** A separate template will be provided for the final report which will also include a financial self-certification form.
Annexe	Annex A: Key milestones table update

Key milestones

1. **In addition to updating the key milestones table in annex A, in this section, provide details of any significant milestones which have not been met with information on why they have not been met, along with mitigating actions.**

Project delivery and outputs

2. **In this section, detail the key achievements of the project to date.**

The project team has been assembled and is working well.

The initial assessment of UK capacity to deliver composites training has been carried out and an international assessment is to follow.

Work is ongoing with the National Composites Centre to understand its training needs and how it might use the sort of curriculum that that this project will develop.

A draft Composite Curriculum Proposed Structure has been generated based around a series of 54 Masters level 2 Credit Point units and an introductory core of 5 x 2 CP units at UG level to allow learners with no prior background in composites to access the higher level material. The 54 masters level units are assembled into nine blocks of six units each covering Materials, Product Design A & B, Manufacturing Processes A & B, Manufacturing Operations A & B, Performance A & B. This draft structure has been disseminated to academic institutions and other key stakeholders for feedback.
An open meeting was held on 22nd May to present the project and the proposed curriculum structure to potential academic partners. Invitations went out to all those institutions that had been identified as providing a significant level of composites education. Representatives of eight universities attended and two additional

institutions gave their apologies and asked to be kept informed of developments. The institutions we are currently working with are Cardiff, Cranfield, Imperial, Sheffield, Southampton, Wrexham Glyndwr, Ulster & UWE in addition to the lead institutions of Bristol and Plymouth.

It is our belief that the wider aims of developing the capacity of the UK academic sector in composites education requires a collaborative approach across multiple academic groups. To that end a Draft memorandum of Understanding has been circulated to all the institutions that expressed an interest in being a part of this activity and we are currently awaiting feedback. It is our intention to develop a group of collaborating institutions that after the end of this project will continue to work together to deliver common aims.

Based on the current proposed structure (which may be subject to change based on input from our potential academic collaborators) we have started to populate the curriculum structure with Unit Descriptions and second level plans. Roughly half of the Unit Descriptions have been prepared by Plymouth and Bristol and as a first step towards developing collaboration a request has been made for volunteers to deliver Unit Descriptions in their areas of expertise. To date three institutions have agreed to provide these. In addition to the Unit descriptions one element of one unit has been worked through to a lecture slide deck and learning exercises so as to be able to estimate the resource requirements to generate new material across the board.

Alongside the formal curriculum development we are collecting together support material and resource material that could become part of a wider package of teaching support. For example the university of Bristol has access to a very large number of sample structures used in teaching demonstrations. These are being catalogued and photographed and the photographs will become part of the resource base for wider dissemination. As the collaborations develop we will widen this to the other institutions involved.

We attended a Composites Leadership Forum meeting on 24th of May that was intended to capture the industry needs and made a presentation about our project. A follow up meeting to cover the industry view in more detail with key stakeholders is scheduled for 2nd August.

3. In this section, provide details of any significant inputs or outputs which have not been met with information on why they have not been met, along with mitigating actions.

It has taken longer than expected to engage with potential academic partners and collaborators although collaboration is now in evidence. This has been mitigated by bringing forward some aspects of the work (such as development of a lecture slide deck and learning exercises) to level out the resource allocation.

4. Has the project encountered any unanticipated challenges (internal or external) in the course of developing the project? If so, outline how these have been dealt with them.

We have lost a key member of staff due to their move outside the academic sector. We made an attempt to mitigate this by a short term contract for another staff member, but that person has also moved on. This has delayed the work on international comparators, but we are currently about to put in place a solution to allow this work to go ahead. In addition we have taken on additional admin resource to collect data and resources and enable the programme leads to focus on the more technical deliverables.

We have found it difficult to get a clear industry view. The CLF meeting on the 24th of May was focused at too low a skills level to be useful to us. To mitigate we have used the NCC as a surrogate industry view and made direct contact with a number of industry people to check that our draft curriculum would meet their needs, and the meeting on the 2nd of August should give us the clarity that we need.

5. Has there been any change in the key partners involved in the project compared to those listed in the business case submitted to HEFCE in September 2017? If so, provide full details and reasons for changes.

Terms and conditions
6. Please confirm the following terms and conditions, as outlined in the award letter, are being adhered to. Where this cannot be confirmed, please provide additional information.

Funding cannot be used to fund business support activity.	Confirm
All provision must commence no later than the 2019/20 academic year.	Confirm

Finance and Risk

7. **Complete the second row of the table below.**

Total Catalyst funding awarded	£200,000
Catalyst funding received from HEFCE/OfS up to monitoring date of 31 July 2018	£133,334
Catalyst funding spent by monitoring date	
Is the project on track to spend the full awarded Catalyst funding by 28 February 2018?	Yes/No

8. **Where there is a different between the funding received and funding spent and/or the project is not on track to spend the full award by February, provide a brief narrative on why this is the case and confirm a date by when the current funding provided will be spent. The OfS is unable to provide funding in advance of need and so we may seek to re-profile the timing of future payments..**

9. **Has there been any change in the investment profile as outlined in the business case submitted to HEFCE in September 2017? If so, provide full details.**

10. **Where funding was detailed in the leverage section of the business case submitted to HEFCE in September 2017, provide an update on the status of this funding.**

11. **Has there been any change to the risk status of the project? If so, provide full details.**

Annex A: Updated key milestones

Target	Key milestone	Key risks	Actions to mitigate risk	Completion date	Outcome	July 2018 Update
1	Conclusion of Curriculum mapping exercise	Poor engagement and buy-in from partner HEIs	Attract buy-in of curriculum mapping exercise through existing network channels via EPSRC Future Composites Manufacturing Research Hub and the British Composites Society	March 2018	Results will be used to inform availability and level of learning in core composite areas of design, stress, materials and manufacturing.	Engagement has generally been positive once the collaborative aspects of the process have been clarified
2	Demand and gap analysis through structured consultation with industry and HEIs	Lack of wide agreement on overall curriculum and content	Mitigated by early establishment of academic and industrial oversight. NCC will act as a conduit to engage industry buy-in and engagement.	April 2018	Verification and validation that curriculum is fit for purpose and prioritise response to gaps appropriately.	To date we have had no negative comments on the draft curriculum that has been developed. Positive feedback has been received from the NCC on the appropriateness of the material.
3	Development of contextual learning objects and materials incl. NCC based case studies	Identifying and unlocking the people with the right skills to deliver the required academic/teaching materials from their days jobs at 4the right time, and manage development to time and cost	Take early steps to identify and secure the release of key individuals for the necessary timescales.	October 2018	A strong portfolio of work-based learning material that can be initially piloted at the NCC through their workforce development schemes.	Good progress is being made in fleshing out the curriculum, collecting and developing teaching resources and in close liaison with the NCC to capture case study material.

4	Pilot curriculum at National Composites Centre	Clash of schedules due to University teaching timetable and NCC recruitment activities.	Take early steps to engage with UoB and NCC to schedule block delivery of content and ensure resources are available.	November-December 2018	Lessons learnt and feedback to improve learner experience before making content more widely available.	Planning is ongoing to achieve this.

Appendix 8- Monitoring report February 2019

Catalyst Fund: Closing the skills gap and supporting the Industrial Strategy through curriculum development

Final Report

Lead HE Provider	University of Bristol
Project title	Composites Curriculum Development
Project code	N12
Contact name	Laura Rhian Pickard
Email	laura.pickard@bristol.ac.uk
Tel No.	0117 3315538
Date report due	**28 February 2019**
Date report submitted	27 February 2019
Frequency for reports to be submitted to OfS:	The project will be monitored formally at two points: • *31 July 2018 - Interim monitoring report.* • **28 February 2019 - Final report** • 31 May 2019 – Final report updated with self-certification
Attached annexes	**Annex A: Updated key milestones and risks** The table submitted with the original business case, as updated in the July interim report has been provided. **Annex B: Financial self-certification form** This will be provided in May.

Project overview
1. **Provide a synopsis of your project, including key themes, key words (maximum of five) and link to project website (if applicable).**
Keywords: Composites, skills, workforce, growth, industry
Website: https://www.fose1.plymouth.ac.uk/sme/composites/
Synopsis: The aim of this project is to generate an industrially relevant and academically rigorous curriculum which could be deployed to tackle the significant skills gap in composites professionals, vital for delivering on the UK's National Composite Strategy and allowing the industry to grow to its full potential, forecast by the Composites Leadership Forum to grow by a factor of 5 by 2030. A Masters' level curriculum of short, industrially focused units has been specified and a small number of trial units developed. Engagement of academics in this novel collaborative curriculum development, utilising each institution's

expertise, has been very good and feedback from industry and participants in pilot units has been positive. The consortium are investigating numerous options for developing this further and have begun to put plans in place for the next stage.

Project delivery and outputs

2. With reference to your original business case, please detail to what extent the following have been met, along with any mitigating actions taken.

a) Aims and objectives

Identify composites learning provision from leading HE providers- available courses and summaries of their content have been identified and recorded. The data is now being verified and options for user-friendly presentation are being considered. Additionally, numbers of students are being recorded in order to refine our estimates of the current provision of persons with suitable education in composites, particularly at Masters' level.

Comparison with international benchmarks- this work is underway. The person responsible has moved to a new job so is completing the task as an external contractor.

Generate a framework identifying the material that should be included in a composites curriculum- a curriculum is in place and feedback from both academia and industry has been positive. Descriptions for each short, 2 day unit, are being written, with 47/59 completed and the remainder nearing completion. Reviews are now underway and the first sets of feedback have been received.

For a limited number of units, develop delivery material and trial that material- a preliminary pilot at the National Composites Centre using material from the 5 core (introductory) units was delivered and feedback was positive. A second pilot of a limited selection of core material was carried out at the University of the West of England during a Continuous Professional Development course. Responses were positive again and detailed feedback questionnaires were completed. Two further pilots, of full units from the main curriculum, will be carried out with the National Composites Centre in March and early April. In addition to this, trial material for two additional units will be developed by the University of the West of England and the National Physical Laboratory, subject to invoices being received from these two institutions in a prompt manner to allow time for this to proceed. These units may also be trialled if time permits.

Identify resource requirements to deliver the full set of teaching and associated supporting materials- a resource of industrial case studies and sets of photographs and videos which may be used in teaching have been compiled. In addition, a material supplier has agreed in principle to provide samples for use in teaching when the full course becomes a reality. An approximate calculation of the human time required to develop the full curriculum has been made and will be refined based on the time taken to develop material for each of the trial units.

Identify a sustainable structure by which ongoing delivery of the composites curriculum could be achieved and scaled to the industrial demand- an estimate of industrial demand has been made based on the UK's National Composites Strategy and discussions are underway with industrial representatives to refine that estimate. A 'train the trainer' scheme is under consideration, which may be synergistic with the National Composites Centre's existing scheme. Discussions with the National Composites Centre, National Physical Laboratory, High Value Manufacturing Catapult and other potential partners regarding the next steps are underway. Options for IP have been discussed and it was concluded that expert opinion should be sought.

b) Key milestones

Curriculum mapping exercise- data has been gathered on composites courses in the UK, in academia and industrial training schemes. With a focus on masters level courses, data is currently being reviewed to check accuracy and additional information on student numbers is being sought.

Demand and gap analyses- response of industry and academia to the proposed curriculum has been positive, and the unit description review process is intended to highlight any gaps. The demand from industry for suitably educated composites professionals has been estimated, but would benefit from refinement based on figures for staff levels in previous projects in the composites industry. The National Composites Centre and contacts at commercial organisations are currently researching this.

Contextual learning objects, materials and case studies- the resource of industrial case studies, many as written by composites companies, covers a range of industries. Images, videos and lecture slides for the trial units have been collated and will be made available. A material supplier has agreed in principle to provide physical samples when the course is running. Universities such as Bristol have many physical parts of varying sizes which are used as examples in teaching.

Pilot curriculum with the National Composites Centre- the first stage pilot with core material was successfully completed, as was the UWE pilot. The second stage pilots, with material from the main curriculum, will be delivered in late March and early April at the National Composites Centre, to a class of staff from NCC and their member companies. Detailed feedback will be sought through questionnaires and lectures will be recorded if all present consent to this.

c) Significant inputs and outputs

Curriculum map output- see above, the data has been gathered and needs to be verified and presented in a user-friendly manner.

Curriculum framework design and specification- this has been done, with input from industrial partners as well as academics from numerous different institutions. The resulting curriculum has a core set of 5 introductory units and 54 specialised units (number may change during review process) arranged in sets of 6 under industrial themes. Unit descriptions for all of these will be provided by the end of the project, with the vast majority already complete and some already reviewed. Each unit is intended to be delivered as a 2 day course with an optional assessment. These units can be combined as appropriate for a given business or project, or taught separately to suit the demand from industry.

Low cost learning objects and resources- many of these are already in place, as discussed above, and lecture notes, practical session guidelines and outlines for assessments from the trial unit development will be added to this by the end of the project.

Pilot curriculum at National Composites Centre- first stage complete, second stage to be done in March and April. Anonymous feedback questionnaires from the second stage will provide material for evaluation of the units, data will be made available at the end of the project. Questionnaires from the pilot at UWE have already been analysed.

Lessons learnt catalogue of learning objects and case studies- case studies are available under the learning objects output above. IP matters require advice from a legal expert. The consortium have suggested that an initial recommendation be sought to inform discussion, with finalizing of licensing agreements to be done in the next stage of the curriculum development, once trial units are available (these will contain no protected IP) to act as examples.

3. Has there been any change in the employers and key partners involved in the project compared to those listed in the original business case? If so, provide full details and reasons for changes.

As in the original business case, the lead institution remains the *University of Bristol*, with the *University of Plymouth* as co-lead on the project and the National Composites Centre as a key partner.

As the purpose of the project is to develop a collaborative curriculum with many institutions contributing in their area of expertise, discussions have included the following institutions, many of whom have contributed or agreed to contribute unit descriptions (*italics*). No funds have been transferred to any of these institutions:

Advanced Manufacturing Research Centre
University of Bath
University of Bolton
Cardiff University

Cranfield University
Imperial College London
National Physical Laboratory
University of Nottingham
Queen Mary University of London
University of Sheffield
University of Southampton
Ulster University
University of the West of England
Wrexham Glyndŵr University
Yeovil College University Centre

The University of the West of England has also hosted one of the unit delivery trials and have quoted to develop material for a trial unit. This will involve payment, which has not yet been made.

Hexcel Composites have agreed in principle to provide material samples for use during teaching and have contributed case studies. GE Aviation, BAE Systems, Dowty Propellers (GE) and Airbus have expressed interest in providing feedback on the detailed curriculum.

Terms and conditions

4. Confirm that the following terms and conditions, as outlined in the award letter, are being adhered with.

Funding cannot be used to fund business support activity.	**Confirmed**
All provision must commence no later than the 2019/20 academic year.	**Confirmed**

5. If any terms and conditions have been breached, provide a full explanation.

N/A

Finance and Risk

6. Complete the table below:

Total Catalyst funding awarded	£200,000
Catalyst funding received from HEFCE/OfS up to 28 February 2019	£133,334
Unspent Catalyst funding	£27609.46 remaining from Tranche 1 on 20/02/2019
Total project spend (from all sources)	£TBD, see May update

7. If there is any underspend against the Catalyst funding, provide details and give clear reasons why this has occurred. The OfS will seek to recover any unspent funds.

The project is not yet complete. Future expenses for which we do not yet have estimates include two further pilot units to be delivered at the National Composites Centre in March and April, development of at least one additional unit of material- to be developed by the National Physical Laboratory- and a final full consortium meeting in April.

We also intend to request an expert opinion from a legal professional specialising in IP regarding the options for the future, which will no doubt incur a cost.

It seems likely at this stage that there will be significant underspend, though exact figures cannot be given until the project completes. This is partially due to a pause in work while replacement staff were recruited, leaving limited time to finish the project and hence reducing both staff and unit development costs, as time limitations restricted the number of units which could be worked upon. There is also a large discrepancy between our estimate of unit development costs and the amounts charged by organisations such as the University of the West of England.

Any unspent funds will of course be returned to OfS. At this stage we feel it appropriate to restrict the project to Tranche 1 funding only, and ask that Tranche 2 be cancelled, allowing OfS to redirect the funds to other areas.

A budget summary is provided at the end of this document.

8. Was there any change in the overall investment package for the project, e.g. have investment partners or funding amounts changed from the original business case? If so, provide details.

No overall change. Colleagues from outside Bristol and Plymouth who are undertaking paid work (such as developing material for trial units) are doing so on a strict payment for defined work package basis.

9. Where funding was detailed in the leverage section of the original business case submitted to HEFCE in September 2017, provide an update on the status of this funding.

N/A

10. Was there any change in the risk status of the project? If so, provide full details.

Staffing challenges have been problematic, though we now have a dedicated team working hard to deliver all project objectives.

IP issues require consideration by experts rather than discussion by academics. We are seeking a neutral, external expert to provide a recommendation as a first stage, which will inform discussions in the future. We are aware that this project is funded by the UK taxpayer and hence chose not to use a global license such as Creative Commons at this stage. This matter needs further discussion.

Challenges

11. What challenges or setbacks did your project experience? How were these addressed?

Staffing challenges, as mentioned above, have been a major issue. These were addressed by recruiting a student at the close of an EngD with a knowledge transfer focus on a full time basis and a University of Bristol project manager on a part time basis. Professor Potter has delayed retirement until the closure of this project.

Some areas of the curriculum require very specialized expertise. It was necessary to seek out suitable experts and persuade them to contribute unit descriptions for their area of specialization. Happily, in some cases this resulted in their joining the group and making very useful contributions beyond the unit descriptions.

As the work is being carried out by volunteers across many institutions, in some cases individuals have over-committed and found themselves unable to carry out all the tasks originally volunteered for, resulting in the few unit descriptions remaining incomplete. These have all been reassigned, and if any remain incomplete by mid March then experts local to Bristol or Plymouth- who can be reminded in person- will be found. Fortunately most of the outstanding topics can be covered by these two organisations.

Obtaining figures from industry for staffing requirements, in order to refine our estimates of the demand for qualified personnel, has been and continues to be a challenge. We met with training managers at Nottingham, but were disappointed to find their time horizons too short for our purposes. We are working with the National Composites Centre and personal contacts in industry in an attempt to address this. The trial units to be delivered at NCC will also provide an opportunity for us to ask participants from their member companies if they can provide us with these figures.

Dissemination

12. Outline the project's dissemination plans.

A report will be compiled for external dissemination, along with data from the curriculum mapping exercise, international benchmarking, demand and resource requirement estimates and feedback questionnaires. This will be distributed to all contributing organisations and made openly available online.

The report will include recommendations for future development of this work.

Material, including lecture slides, the case study resource, photographs, videos and all other items which are intended to form part of the final curriculum will be made available to institutions which are part of this project or any future continuation of this project, pending an agreement being reached on IP.

Sustainability and wider impact

13. Outline the sustainability plan for your project's key activities.

We have found many academics with interest in seeing this project reach fruition and determination to achieve this. Various options are being discussed for the next stage of the work. Ultimately, it is hoped that a course based on this curriculum will be self-funding, by commercial uptake of the courses. Discussions are ongoing with numerous interested parties.

We are exploring the opportunities for funding a new champion who will take the work beyond the retirements of the current leads. An appropriate funding mechanism might be a personal fellowship, perhaps funded by NCC, RAEng or HVMC. A preliminary proposal has been sent to HVMC.

14. Is the project having tangible beneficial impact on students and employers, and has it improved/enhanced collaborative relationships between higher education and employers?

Participants who attended the pilot courses responded very positively.

Collaboration between different higher education institutions has been significantly improved. A collaborative curriculum is a novel approach and has been well received and developed by volunteers at many institutions. There is also improved collaboration with the National Composites Centre and National Physical Laboratory.

Industrial partners have shown interest in the curriculum and in sending staff to the pilot units. As this is intended to meet a clear- and urgent- need within the composites industry, as the project progresses to the next stage and the course becomes a reality we expect to see very significant benefits to industry.

15. How will the key activities continue to support skills developments for both students and employers beyond the funding period?

The intention is to develop this curriculum into an offering which can be tailored- through picking and choosing of short units- to the needs of different groups and organisations within the composites industry and delivered as required to meet demand. Discussions are underway with the HVMC, NCC and NPL along with other partners.

It is anticipated that a set of teaching support materials will be shared amongst UK academics in the composites sector.

16. Detail any wider impacts of the project not covered in the sections above.

Failure to put in place the number of personnel required by the composites industry will compromise the sector growth forecast by CLF in Composites Strategy 2016. This project and follow on activities are intended to tackle this problem, facilitating delivery of growth in the composites sector and related industries and hence making a greater contribution to the UK economy.

Additional information

17. Provide the key achievements and lessons learned from the project, which we may cite in our publications or on our website, not already covered in the sections above.

Multiple universities have contributed to a collaborative curriculum.

The specified curriculum is industrially focused, flexible, and aimed squarely at a large and growing skills gap in a key UK industry.

18. Do you have any additional comments on your project, or any general feedback for the OfS? For example, are there any other key points which may support continuing policy development?

Annex A: Updated key milestones

Please just provide a high level status report and confirm any date changes. Further details should be provided in the main body of the report.

Target	Key milestone	Key risks	Actions to mitigate risk	Completion date	Outcome	July 2018 update	February 2019 update
1	Conclusion of Curriculum mapping exercise	Poor engagement and buy-in from partner HEIs	Attract buy-in of curriculum mapping exercise through existing network channels via EPSRC Future Composites Manufacturing Research Hub and the British Composites Society	March 2018 March 2019	Results will be used to inform availability and level of learning in core composite areas of design, stress, materials and manufacturing.	Engagement has generally been positive once the collaborative aspects of the process have been clarified	Pause in work due to staffing changes has led to some initial data becoming out of date, requiring work to be re-done. This is underway and will be completed soon. Universities will be asked to supply student numbers for taught courses in composites at Masters level or above, to refine estimates of gap in provision of qualified professionals.

Target	Key milestone	Key risks	Actions to mitigate risk	Completion date	Outcome	July 2018 update	February 2019 update
2	Demand and gap analysis through structured consultation with industry and HEIs	Lack of wide agreement on overall curriculum and content	Mitigated by early establishment of academic and industrial oversight. NCC will act as a conduit to engage industry buy-in and engagement.	April 2018 April 2019	Verification and validation that curriculum is fit for purpose and prioritise response to gaps appropriately.	To date we have had no negative comments on the draft curriculum that has been developed. Positive feedback has been received from the NCC on the appropriateness of the material.	Unit descriptions for almost all of the draft curriculum have been written and reviews are now taking place. Some modification expected based on the review process.

3	Development of contextual learning objects and materials incl. NCC based case studies	Identifying and unlocking the people with the right skills to deliver the required academic/teaching materials from their days jobs at the right time, and manage development to time and cost	Take early steps to identify and secure the release of key individuals for the necessary timescales.	October 2018 Trial unit teaching material to be completed April 2019. Case study resource, inventory of photographs and set of videos already complete.	A strong portfolio of work-based learning material that can be initially piloted at the NCC through their workforce development schemes.	Good progress is being made in fleshing out the curriculum, collecting and developing teaching resources and in close liaison with the NCC to capture case study material.	The curriculum structure is complete and most unit descriptions are done. Teaching materials for a small number of trial units are currently under development. Materials from the first two pilot studies are available. A resource of case studies has been compiled along with a set of videos and an inventory of photographs which can be used. Physical objects are available at University of Bristol. Hexcel have agreed in principle to provide samples of their fabrics and

Target	Key milestone	Key risks	Actions to mitigate risk	Completion date	Outcome	July 2018 update	February 2019 update
							other materials for the course.
4	Pilot curriculum at National Composites Centre	Clash of schedules due to University teaching timetable and NCC recruitment activities.	Take early steps to engage with UoB and NCC to schedule block delivery of content and ensure resources are available.	November-December 2018 Final pilot concludes on 5th April 2019 Analysis of feedback to be complete by 12th April 2019.	Lessons learnt and feedback to improve learner experience before making content more widely available.	Planning is ongoing to achieve this.	First pilot at NCC was well received. Second pilot at UWE also went well and quantitative feedback was gathered by questionnaire. Further NCC pilots of two full units to be delivered in March and early April, feedback questionnaires will again be deployed.

Annex B: Financial Self-certification (for May 2019 submission)

Provider's legal name	University of Bristol
Project title	Composites Curriculum Development
Catalyst Fund project code	N12
Statements	I have reviewed the above named project and confirm that: • The HEFCE/ OfS grant for this project has been used for the purposes provided. • The lead provider has complied with any specific conditions attached to the grant. • The lead provider has taken reasonable steps to achieve value for money.
Signature	
Printed name	
Job Title	
Date	

Please note, this self-certification must be signed by the accountable officer (usually the Head of Provider), or an appropriate deputy with the necessary delegated authority.

HEFCE Composites Curriculum Development Project Budget Summary February 2019

Income				
	Tranche 1	£ 133,334		
	Tranche 2*	£ 66,666.00		
	Total	**£ 200,000**		
DI Salaries		***Actual to date***	***Committed***	***Total***
	Academic	£ 19,628.47	£ 8,399.60	£ 28,028.07
	Professional/admin	£ 2,611.24	£ 3,217.28	£ 5,828.52
	Hourly paid teachers	£ 4,940.40	£ -	£ 4,940.40
	Total	**£ 22,239.71**	**£ 11,616.88**	**£ 38,796.99**
DI non salary		***Actual to date***	***Committed***	***Total***
	Consumables	£ 150.26	£ -	£ 150.26
	Catering	£ 306.93	£ -	£ 306.93
	Room hire costs	£ 1,030.80	£ -	£ 1,030.80
	Casual staff costs	£ 23,257.04	£ 10,994.52	£ 34,251.56
	External fee for international benchmarking	£ -	£ 2,000.00	£ 2,000.00
	UWE Unit Development	£ -	£ 4,188.00	£ 4,188.00
	NPL Unit Development	£ -	£ -	£ -
	Total	**£ 24,745.03**	**£ 17,182.52**	**£ 41,927.55**
Plymouth costs**			***Committed***	***Total***
	Travel		£ 5,000.00	£ 5,000.00
	Staff		£ 11,394.00	£ 11,394.00
	Estates		£ 1,731.00	£ 1,731.00
	Indirect costs		£ 6,875.00	£ 6,875.00
	Total		**£ 25,000.00**	**£ 25,000.00**

Remaining budget[+] **£ 94,275**

* to be paid at a later stage

** Plymouth to invoice Bristol

[+] including Tranche 1 and Tranche 2

Appendix 9- Detailed unit descriptions

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Introduction to Composites
Level (Credit points)	H (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with composites with a general introduction to the core concepts in understanding and applying composites in engineering applications.

Core subjects to be covered

1. History of composite materials
2. History of synthetic composites
3. Why use composites
4. Advantages and disadvantages
5. Fibres
6. Reinforcement forms
7. Resins
8. Mechanical properties
9. Other properties
10. Designing with composites
11. Predicting performance
12. Manufacturing processes
13. Shaping reinforcements
14. Traditional processes
15. High performance composites processes
16. High rate processes
17. Applications in aerospace
18. Applications in automotive
19. Applications in renewable energy and other sectors
20. Sustainable composites

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the development of composite materials
2. Identify the advantages and limitations of these materials
3. Give learners an understanding of the range of materials and process options
4. Provide the learners with an understanding of current and potential applications of composites

Statement of learning outcomes

Learners will be able to:

1. Provide a basic overview of the development of composite materials and their applications
2. Understand some of the positive and negative aspects of composites and how these impact on design and application of composites
3. Understand some of the issues and methodologies involved in the selection and design of composite products

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

University of BRISTOL — UNIVERSITY OF PLYMOUTH

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Composite Constituents
Level (Credit points)	H (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit “Introduction to Composites” to provide Learners with an understanding of the materials that are used in combination to manufacture composite materials and the products made from them.

Core subjects to be covered

1. Glass fibres, manufacture and properties
2. Carbon fibres, manufacture and properties
3. Aramid fibres, manufacture and properties
4. Other fibre types, manufacture and properties
5. Reinforcement forms, unidirectional materials
6. Reinforcement forms, bidirectional materials
7. Reinforcement forms, multidirectional and 3D materials
8. Thermosetting resins, history and resin types
9. Thermosetting resins, curing and cure predictions
10. Thermosetting resins, property development during cure
11. Thermosetting resins, cure monitoring
12. Thermosetting resins, attempts at toughening
13. Thermoplastic resins, commodity types
14. Thermoplastic resins, high performance types
15. Matrix resin mechanical performance & properties
16. Selecting the right fibre, reinforcement form and resin type
17. Core materials, foams
18. Core materials, honeycomb
19. Metal and ceramic matrix composites
20. Sustainable resources for fibres and matrices

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the fibres used in composites and how their manufacture and structure define their properties
2. Show how fibres are built up into useful forms of reinforcement
3. Identify classes and types of matrix resins by their chemistry and properties
4. Provide the learners with an understanding of how to select combinations of fibre, reinforcement type and matrix to meet specific applications
5. Introduce learners to forms of composite materials using non-polymeric matrices

Statement of learning outcomes

Learners will be able to:

1. Relate the composition of a composite to its mechanical properties
2. Understand the positive and negative aspects of different classes of fibres, matrix and other constituents of composite materials
3. Understand some of the issues and methodologies involved in the selection of constituents to deliver specific aspects of performance

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Manufacturing of composite products
Level (Credit points)	H (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit “Introduction to Composites” and “Composites Constituents” to provide Learners with a good understanding of the methodologies used in the manufacture of composite products.

Core subjects to be covered

1. Drafting practices and ply direction control rosettes
2. Mapping reinforcements to required geometries
3. Reinforcement deformation
4. Drape models and conformability
5. Reinforcement preparation, nesting
6. Process availability and process selection
7. Manufacturing instructions
8. Prepreg processes, manual reinforcement lay-up
9. Prepreg processes, automated reinforcement lay-up
10. Prepreg processes, consolidation
11. Prepreg processes, preparation for moulding
12. Prepreg processes, vacuum bag and autoclave,
13. Prepreg processes, compression moulding
14. Prepreg processes, cure.
15. Dry fibre processes, pultrusion and filament winding
16. Dry fibre processes, rigid tool variants of resin infusion
17. Dry fibre processes, flexible tool variants
18. Tooling materials and tool design
19. Demoulding and post moulding non-destructive inspection
20. Machining and finishing processes

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the processes used in the manufacture of composite products
2. Give learners an understanding of the range of materials and process options
3. Give learners the tools to compare processes and chose the most appropriate manufacturing routes
4. Provide the learners with an understanding of methods to control the manufacturing processes

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of composites manufacturing and control processes
2. Understand the positive and negative aspects of each suite of processes and how these impact on design and development of composite products
3. Understand some of the issues and methodologies involved in the manufacture of robust, high quality and defect-free composite products

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Product Design
Level (Credit points)	H (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the methodologies used in the development of composite products.

Core subjects to be covered

1. The product design cycle
2. The product design team
3. Cost and risk through the product design cycle
4. Requirements capture
5. Specification development
6. Stage gates and review processes
7. Conceptual or outline design
8. Methods for generating design concepts
9. Costing in the design process, including minimising wastes
10. Geometry, materials, process decisions
11. Detailed design methods
12. Estimating performance of composite structures
13. Back of the envelope and initial analytical methods
14. Detailed analytical methods
15. Numerical methods and FEA
16. Development of production costs
17. Prototyping
18. Testing and validation
19. Transitioning to production
20. Lessons learned - capturing product development knowledge.

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the composites product design process in an industrial context
2. Identify the stages in the process and the importance of following a clear process
3. Enable the learners to contribute to product design teams as quickly as possible
4. Provide the learners with an understanding of both best practice and the pitfalls in composites product development

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the processes involved in the design of composites products
2. Understand the staged development of successful composite products
3. Understand some of the issues and methodologies involved in the testing and validation of composite products prior to volume production

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Properties of Composites
Level (Credit points)	H (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units “Introduction to Composites” and “Composites Constituents” to provide Learners with a more in depth understanding of the properties and performance of polymer matrix composite materials and the products made from them.

Core subjects to be covered

1. Properties of a single fibre and a dry tow of many fibres
2. Properties of a tow when a matrix is added
3. Properties of a unidirectional laminate of many tows
4. Properties of a laminate at an angle to the fibres
5. Properties of biaxial and pseudo-isotropic laminates
6. Properties of short fibre composites
7. Properties of 3D reinforced composites
8. Properties of post-use recovered fibres
9. Predicting strength and stiffness of arbitrary lay-up laminates
10. Strength and stiffness through thickness
11. Toughness of composite laminates
12. Effects of temperature on properties
13. Effects of moisture on properties
14. Effects of other environments on properties
15. Effects of high strain rates on properties - impact
16. Effects of long loading time on properties - creep and fatigue
17. Electrical properties of composites
18. Fire performance of composites
19. Test methods for composites
20. Data bases of composites performance data.

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with a more detailed view of the development of mechanical properties in composite materials
2. Demonstrate how laminate mechanical properties may be predicted from fibre and matrix properties
3. Demonstrate how laminate properties vary with loading direction
4. Provide the learners with an understanding of non-mechanical properties of composites and the importance of these in product design

Statement of learning outcomes

Learners will be able to:

1. Design a laminate to achieve a specific set of basic mechanical properties
2. Understand the impact of externally applied loads on that laminate
3. Appreciate the likely non-mechanical properties of the laminate that has been designed

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Materials
Unit title	Polymeric Matrices
Level (Credit points)	M (2)
Unit director	Dr Edward Archer, Dr Alistair McIlhagger, Ulster University

Unit description

This unit forms part of the Masters level Composites Curriculum. It enables learners to critically appraise alternative thermoplastic and thermoset conversion and fabrication processing routes. Through analysis of the mechanical and physical characteristics of polymers, students should be capable of developing an appropriate strategy for selection of processing routes for a range of material systems and applications. The course will impart an understanding of the polymers at a basic molecular level, but be delivered from a polymer composite engineering perspective rather than polymer chemistry.

Core subjects to be covered

1. Introduction to Polymers
2. Mechanical Properties of Polymeric Materials
3. Molecular arrangement
4. Viscoelasticity and Toughness
5. Crystallinity and Glass transition
6. Thermoplastic Composites
7. Basic principles of operation of injection moulding, blow moulding, extrusion, etc.
8. Productivity issues
9. Temperature control and heating/cooling
10. Thermoset matrix properties
11. Thermoplastic matrix properties
12. Time-dependent response and creep
13. Environmental stress cracking
14. Polymer Testing and Identification
15. Thermal analysis and rheology
16. Recycling strategies
17. Development areas and future research

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the polymer types used in the composites sector
2. Identify the advantages and limitations of polymer processing methods
3. Explore aspects of polymer testing and analysis methods
4. Provide the learners with information to support the design of polymer composite products with consideration of environmental effects and time-dependent response.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of thermoplastic and thermoset polymer composite fabrication processes and assess the relative potential of alternative process routes for products and their design
2. Understand the features of polymer processes and how these may be optimised
3. Understand the issues and methodologies involved in the selection and design of polymers for composite products

Methods of teaching	6 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Materials
Unit title	Polymer melt viscosity and chemorheology, cure and degradation
Level (Credit points)	
Unit director	Alex Skordos

Unit description

This unit focuses on polymeric matrices and their behaviour during manufacturing operations. The coverage includes physical and chemical aspects of material behaviour, materials state transitions taking place during processing, quantitative models and characterisation methods.

Core subjects to be covered

1. Cure of thermosets
2. Crystallisation of thermoplastics
3. Rheology of thermoplastic matrices
4. Rheology of thermosetting matrices
5. Rheological modelling
6. Cure kinetics
7. Glass transition temperature development
8. Degradation of polymers
9. Material state maps

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with knowledge of polymer material behaviour during the manufacturing of composites
2. Present the main approaches for characterising material behaviour
3. Provide the tools for quantitative analysis of the phenomena governing material behaviour

Statement of learning outcomes

Learners will be able to:

1. Understand the physical and chemical transformation polymers undergo during their processing
2. Use quantitative methods to analyse and predict material behaviour
3. Link polymer behaviour with composites processing

Methods of teaching	6 lectures, 6 computer based tutorials, 2 Lab demos
Assessment details if required	Written assessment (100%)
Timetable information	2 days teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Materials
Unit title	Fibres and moulding compounds
Level (Credit points)	M (2)
Unit director	Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit “Introduction to Composites” and “Composites Constituents” to provide Learners with a good understanding of the manufacture, properties and performance of synthetic reinforcing fibres and the associated moulding compounds.

Core subjects to be covered

1. Background and history of the development of synthetic reinforcing fibres
2. Glass fibres production
3. Glass fibres properties
4. Carbon fibres production
5. Carbon fibres properties
6. Aramid fibres production
7. Aramid fibres properties
8. Other polymeric fibres
9. Regenerated cellulose/lignin fibres
10. Ceramic and boron fibres
11. Metallic fibres
12. Whisker reinforcements
13. Sheet moulding compounds manufacture
14. Sheet moulding compounds design and applications
15. Bulk (Dough) Moulding compounds manufacture
16. BMC design and applications
17. High performance moulding compounds development (HexMC/Forged composites)
18. High performance moulding compounds design and applications
19. Flow characterisation of moulding compounds
20. Selecting fibres and moulding compounds by application and manufacturing process
21. Future development aims and opportunities

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the development of the development, production and performance of different classes of synthetic reinforcing fibres
2. Provide Learners with an overview of how to select the appropriate fibre for different applications
3. Provide learners with a good appreciation of the different forms of moulding compounds and where they are appropriately used

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the capabilities of the available synthetic reinforcing fibres
2. Select the appropriate fibre and moulding compound type for particular applications
3. Understand the design characteristics of the different classes of moulding compounds

Methods of teaching	7 lectures and associated demonstrations and exercises
Assessment details if required	Written assignment
Timetable information	2 days of teaching in a block.

Composites Curriculum – Unit information

Taught block title	Materials
Unit title	Characterisation techniques
Level (Credit points)	
Unit director	James Kratz

Unit description

This unit focuses on experimental techniques to characterise the thermo-mechanical property development of polymeric matrices and microstructure constituents of fibrous composites.

Core subjects to be covered

Thermo-mechanical properties 1. Thermo gravimetric analysis 2. Differential Scanning Calorimetry 3. Laser flash analysis/ Guarded hot plate 4. Rheometry/ Dynamic mechanical analysis 5. Thermo mechanical analysis 6. Dilatometry / PVT methods	Microstructure constituents 7. Optical and electron microscopy 8. X-ray computed tomography

Statement of unit aims

The aims of this unit are to:

1. Introduce the main approaches for characterising polymer material behaviour
2. Describe instrument operating principles and sample preparation methods

Statement of learning outcomes

Learners will be able to:

1. Identify relevant characterisation techniques to measure thermo-mechanical properties of polymers and microstructural properties of fibrous composites
2. Define test methods and matrices
3. Interpret experimental results

Methods of teaching	8 lectures, 6 Lab demos
Assessment details if required	Written assessment (100%)
Timetable information	2 days teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Materials
Unit title	Dry fabrics and prepregs
Level (Credit points)	M (2)
Unit director	Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces learners to the processes used in the manufacture of both dry and preimpregnated reinforcements and how the processes used in the manufacture of reinforcements impact on other aspects of composites manufacturing

Core subjects to be covered

1. Introduction, background and history
2. Weaving processes for reinforcements
3. Weave structure types 2D
4. Weave structure types tailored 2D
5. Weave structure types 3D
6. Simulation of textile structures
7. Stitching and tufting
8. Non-crimped fabric processes
9. Braiding processes
10. Tailored fibre placement processes
11. Felts and other non-wovens
12. Aligned discontinuous reinforcements
13. Binder application processes
14. Prepreg manufacture process
15. Solvent methods
16. Film methods
17. Interlayered prepreg
18. Characteristics of prepregs under mechanical load
19. Reinforcement selection process

Statement of unit aims

The aims of the unit are to:

1. Provide learners with an overview of manufacturing processes for dry and impregnated reinforcements
2. Give learners an understanding of the range of reinforcement options available
3. Provide learners with an overview of how to select reinforcements for particular structures

Statement of learning outcomes

Learners will be able to:

1. Demonstrate an understanding of the range of reinforcement types commercially available
2. Understand how the reinforcements are manufactured and how those processes may impact on composites manufacturing processes
3. Understand how materials are selected for the manufacture of specific products

Methods of teaching	8 lectures, 1 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Materials
Unit title	Characterisation of fabric reinforcements
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit “Introduction to Composites”, “Composites Constituents” and “Reinforcement Types” to provide Learners with a good understanding of the characteristics of fabric reinforcement, including compressibility, drape and permeability.

Core subjects to be covered

1. Review of fabric reinforcement architectures.
2. Textile terms and definitions.
3. Areal weight, tow count, cover factor, etc.
4. In-plane characterisation (fabric testing)
5. Through-plane characterisation for single or multiple layers (volume fraction *vs* pressure, nesting)
6. Thermal characterisation of fabrics
7. Drape (natural) and conformability (assisted) to curved surfaces
8. Automated handling of fabrics
9. Permeability to liquid resin/molten polymers
10. Process-property-microstructure relationships

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the characterisation techniques for flexible materials.
2. Provide Learners with an overview of the advantages and constraints of differing reinforcement architectures.
3. Give Learners the tools to select a reinforcement which balances manufacturability with the required composite properties.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the range of parameters which define a fabric reinforcement
2. Establish an appropriate testing procedure for each parameter necessary to pre-manufacture handling and composite performance.
3. Understand the issues constraining the use of different fabric architectures.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design A
Unit title	Design Cycle and Requirements Capture
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces learners to the Product Design Cycle, focusing on the evolution of product design for composites, the importance of the early stages in design and requirements capture as a critical part of the design process.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. The purpose of product design
2. The evolution of design for composite products
3. The Design Cycle
4. Learning from errors in design activities
5. Learning from other industries' experience
6. Assessment of Design Requirements
7. Functional requirements
8. Geometry requirements
9. Environmental and operating conditions
10. Duty cycles and loadings
11. Cost issues
12. Programme/Contract issues
13. Regulatory requirements
14. Project appraisal
15. Generating a Design Brief
16. Outline design loop
17. Forced decisions
18. Conceptual solutions
19. Concept challenge
20. Development programmes

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the product design cycle for composites
2. Demonstrate to learners the breadth of information that needs to be captured to deliver a successful design
3. Provide learners with a structure within which to carry out product design

Statement of learning outcomes

Learners will be able to:

1. Confidently capture the required data to carry out a design assessment and produce a design brief
2. Use the design brief to examine potential solutions to the design requirements to deliver an outline design that can be developed through further analysis

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design A
Unit title	Costing in a design environment
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces learners to the principles of costing in a design environment, building on the Unit Design Cycle and requirements capture to provide learners with a more detailed support for costing activities.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Costing in the design process
2. Costing in design assessment
3. Top down costing – the art of the possible
4. Designing to cost target constraints
5. Bottom up costing
6. Built-up labour rates, advantages and disadvantages
7. Cost estimating 1. Materials including consumables and wastes/disposal
8. Cost estimates 2. Direct manufacturing touch labour Hours

1. Cost estimates 3. Supervision/inspection labour
2. Cost estimates 4. Machine/power utilisation
3. Cost estimates 5. Other indirect resources
4. Rework, repair and scrap rate assumptions
5. Activity listing approaches
6. Capturing non-recurring costs
7. Predicting development costs
8. The importance of scenario assessment and “What if?” costing
9. Minimising Non Recurring Costs in design
10. Balancing speed and accuracy

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the importance of costing as part of the design activity
2. Provide learners with a structure within which to carry out costing as part of product design
3. Provide learners with some tools to use in early stage product design costing

Statement of learning outcomes

Learners will be able to:

1. Confidently engage with the need to generate cost estimates as part of the design process
2. Produce first order cost estimates to guide the design process

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

Taught block title	PRODUCT DESIGN A
Unit title	Drawing Practices and lay-up rules
Level (Credit points)	H (2)
Unit director	Martyn Jones/ Prof Richard Day

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides learners with detail on good drawing practices and the basis of ply layup rules. It also will enable students to understand and apply industry standard practice through CAD packages for composite design.

Core subjects to be covered

1. Importance of clear drawings for designers, manufacturers and end users.
2. Different fibre architectures and influence of warp/weft
3. Material properties, (Anisotropic, Orthotropic, Lamina)
4. Ply stacking best practice and drafting rules
5. Laminate orientation codes
6. Ply books
7. Standards and drawing conventions – EN4408-1 to ENG4408-5
8. Ply stacking sequences
9. Importance of balanced layups
10. Ply drop off guidelines
11. Hole positions and influences
12. Laminate draping and darts
13. CAD based composites design packages (such as Catia Composite workbench) for Ply zones, stacking and ply book creation.

Statement of unit aims

The aims of this unit are to:

1. Demonstrate the importance of communicating composites designs
2. Enable designers and manufactures to understand ply drop off areas and transition zones
3. Show how darts can be used to allow adequate draping over curves
4. Allow students to use industry standard software for composite design.

Statement of learning outcomes

Learners will be able to:

1. Fully understand the relevance and importance of composites drawing standards
2. Critically evaluate and scrutinise engineering drawings
3. Be proficient in industry standard drafting CAD packages for drawing.

Methods of teaching	3 lectures, 2 CAD sessions, 1 practical session, 1 direct learning
Assessment details if required	100% assessment (2 assignments at 50/50)
Timetable information	4 days

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design A
Unit title	Design for manufacture
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the concepts of design for manufacture and how those concepts can be applied to the design and development of composite products.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Goals of Design for Manufacture
2. Design for Manufacture guidelines
3. Composites specific guidelines
4. Concurrent design
5. The rule of 10s
6. Minimizing handling
7. Understanding manufacturing problems
8. Design for easy fabrication/assembly
9. Design for fixturing
10. Robust design principles
11. The importance of supply chain reliability
12. Process specific design guidelines
13. DfM in RTM and Resin Infusion
14. DfM in prepreg bag moulding processes
15. DfM for automated fibre placement
16. Acquiring process specific information
17. Check-list approach to Design for Manufacture

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of Design for Manufacture concepts
2. To identify how those concepts can be applied in the context of composites products
3. Provide Learners with some tools to apply in a design environment

Statement of learning outcomes

Learners will be able to:

1. Identify factors that will impact on manufacturability in terms of ease of manufacture for various processes
2. Identify how the costs of manufacture can be reduced by applying concepts of design for manufacture
3. Understand how to capture design for manufacture information for emerging processes

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design A
Unit title	Acceptance criteria, rework, concessions – Designing out defects
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to some aspects of quality in composite components and structures, and how deviations from the design intent have to be handled when dealing with structurally important structures. The principal focus of the unit is the impact of the design process on defects in production, which overlaps with but is not equivalent to Design for Manufacture.The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. The quality assessment process
2. Defining Acceptance Criteria
3. Rework, repair and the concession process
4. Direct costs associated with rework, repair and concessions
5. Production flow disruption and other costs associated with rework, repair and concession
6. Drawing tolerances, what drives them?
7. Manufacturing standards, e.g. for accuracy of ply positions or ply/ply gaps
8. Defining process capability for each step in the process chain
9. Process capability for Manual and Automated processes
10. Achievable tolerances related to materials variability
11. Achievable tolerances related to process variability
12. Impacts of geometrical features on quality Interactions between geometry, part quality and complexity of stress states
13. Inspecting designs for features expected to generate out of tolerance events
14. Methods to reduce the probability of defects arising within a fixed design envelope
15. Estimating the cost of applying methods to reduce defect probability

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of manufactured quality in composites production
2. Clarify the costs of poor quality and the impact of a lack of quality on profitability
3. Provide learners with tools that can help to avoid designs that are prone to defect formation

Statement of learning outcomes

Learners will be able to:

1. Identify appropriate acceptance criteria with regard to process capabilities
2. Examine designs with a view to identifying potential for defect generation
3. Identify amendments to designs to minimise the potential for defect generation

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product design A
Unit title	Standards and certification
Level (Credit points)	H (2)
Unit director	Stefanos Giannis

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the Performance A and B units to provide Learners with a good understanding of the role of composite materials standards and design codes and their use in the certification of composite structures

Core subjects to be covered

1. Introduction
2. Need for Regulations, Codes and Standards (RCS)
3. Role of regulators
4. Role of standardisation bodies and classification societies
5. Standards creation and pre-standardisation work
6. Round-robin validation of test methods
7. Design codes and relation to standards including industry standards e.g. AITM (aerospace) and AASHTO/CIRIA (FRP bridges)
8. Composite materials test standards
9. Interpretation of materials test standards
10. Certification pyramid and product validation chain
11. Acceptable means of compliance in certification of composite structures
12. Statistical interpretation of qualification test data including calibration, errors and uncertainty
13. Design data versus experimental data
14. Role of numerical simulation in certification of composite structures including methodology for ascertaining validity of data from the scientific literature used to inform modelling

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an understanding of the need for suitable Regulations, Codes and Standards (RCS) for composite materials
2. Give learners an overview of the certification process of composite structures in a number of industry sectors
3. Enable learners to analyse qualification test data and obtain appropriate design data

Statement of learning outcomes

Learners will be able to:

1. Interpret and use composite materials standards
2. Choose the right test method and standard for qualifying composite materials and certifying structures
3. Understand how to statistically analyse test data to obtain design data for composite materials

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design B
Unit title	Micromechanics
Level (Credit points)	H (2)
Unit director	Dr. Nuri Ersoy

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with composites with a general introduction to the basic micromechanical methods to predict the thermomechanical properties of unidirectional composites from the corresponding properties of the constituents.

Core subjects to be covered

1. Review of thermomechanical properties of transversely isotropic materials
2. Predicting the composites properties using rule of mixtures
3. Predicting the composites properties using mechanics of materials approach
4. Predicting the composites properties using Self-Consistent Micromechanics
5. Predicting the composites properties using Representative Volume Elements and Finite Element Method
6. Comparison of the thermomechanical and strength properties using predictive micromechanical methods and experimental values

Statement of unit aims

The aims of this unit are to:

1. Review the engineering constants required to define transversely isotropic materials
2. Provide the learners with an overview of the concepts of micromechanical methods to predict the thermomechanical properties of unidirectional, transversely isotropic composites.
3. Provide the learners with an understanding of the causes of discrepancies of the predictions of the micromechanical methods and experimental values.
4. Give learners a feeling of how reliably the predicted values can be used in laminate design and analysis

Statement of learning outcomes

Learners will be able to:

1. Calculate the thermomechanical properties of the transversely isotropic materials using rule of mixtures, mechanics of materials approach and self-consistent field micromechanics
2. Able to construct Finite Element Models of Representative Volume Elements representing unidirectional, transversely isotropic composites.
3. Solve the Finite Element Models by assigning relevant boundary conditions and loads.
4. Interpret and assess the reliability the results of the predictions of micromechanical methods

Methods of teaching	5 lectures, 3 FEA tutorials, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design B
Unit title	Composite laminate design
Level (Credit points)	H (2)
Unit director	Dr. Mahdi Damghani
Unit description	
This unit forms part of the Masters level Composites Curriculum. It provides learners having no/limited knowledge of composite structures with a general introduction to the basics and principles of composite laminate design.	
Core subjects to be covered	
1. Principles of laminate design and design of a composite piece 2. Design and analysis of composite beams 3. Design and analysis of sandwich composite structures	4. Bonded joints 5. Bolted joints 6. Good design practices and design “Rules of Thumb”
Statement of unit aims	
The aims of this unit are to: 1. Provide the learners with principles of laminate stacking sequence design and laminate sizing under various loading scenarios. 2. Provide means of analysing and designing laminated composite beams. 3. Provide means of analysing and designing sandwich structures. The learners will also be exposed to damage mechanisms in sandwich panels and attaching sandwich structures. 4. Provide understanding of stress distribution and structural damage mechanisms in both bonded and bolted joint in composite structures. 5. Provide existing repair techniques for laminate composite structures.	
Statement of learning outcomes	
Learners will be able to: 1. Practically implement composite structures design/sizing and optimisation using hand methods.	
Methods of teaching	6 lectorials (combination of lectures and tutorials).
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Product Design B
Unit title	Stress analysis - classical
Level (Credit points)	
Unit director	Dr. Hamed Yazdani Nezhad

Unit description

The taught unit on Stress Analysis (Classical) comprises of mechanics of stress-strain fields, mechanical deformation and strain energy in fibre-reinforced composite materials and laminates in the presence of unidirectional and woven fibres architecture relying mainly upon the principles of material constitutive equations. The unit includes both elastic and elastic-plastic deformation, and excludes mechanics of damage.

Core subjects to be covered

1. Composite materials
2. Laminated composites
3. Concept of a continuum and continuity
4. Concept of homogeneity
5. Concept of isotropy
6. Elements of vector & transformation of axes
7. Matrix mathematics & tensor algebra
8. Direct strain & Shear Strain
9. General three-dimensional stress
10. Constitutive equation for composites
11. Deformation & strain tensor for composites
12. Viscoelastic effects
13. Stresses: Body and surface forces
14. Stress tensor, principal stresses & invariants
15. Stiffness calculations in composites
16. Strength calculations in composites
17. Conservation of energy
18. Definition of strain energy
19. Constitutive relations for elastic composites
20. Elastic-plastic composites
21. Concept of small scale yielding
22. Crack tip stress fields in composite
23. Techniques for structural analysis & design

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with classes and types of composite materials (particle or fibre reinforced) and laminates
2. Provide learners with theoretical estimation methods for composite stiffness, strain, stress & strength
3. Provide state-of-the-art techniques for composite stress analysis methods and composite structural design

Statement of learning outcomes

Learners will be able to:

1. Categorise classes and types of composite materials and laminated composites
2. Estimate stiffness, strain, stress and strength of composite materials and laminates
3. Understand some of methodologies involved in design of composite structures

Methods of teaching	9 lectures, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Product Design B
Unit title	Stress analysis - FEA
Level (Credit points)	
Unit director	Dr. Hamed Yazdani Nezhad

Unit description

The proposed unit provides conventional techniques for finite element analysis of composite materials and composite laminates under elastic and elastic-plastic conditions, subjected to mechanical and thermal loading, and in the presence of a pre-existing damage, according to the basics given in unit: Stress Analysis (Classical)

Core subjects to be covered

1. Basic FEA concepts and definitions
2. Finite element discretisation
3. Principle of virtual work
4. Numerical quadrature
5. Mathematical models: Linear elastic solids
6. Inversion of Stiffness Matrix
7. Nodal displacement
8. Element Shape Functions
9. Strain-Displacement Matrix
10. Mass Matrix
11. Steps towards FEA of composite laminate
12. Modelling in commercial FEA software
13. Role of fibre orientation in composite laminates
14. Thermal stress FEA
15. Elastic and elastic-plastic FEA modelling
16. Damage FEA modelling

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with sequential steps followed by a FEA giving a concise explanation of each
2. Carry out finite element calculations on composite laminates
3. Provide understanding of the FEA solution for composite materials and structures
4. Understand the engineers role in using numerical results to designing components and the risks (i.e. safety and financial) associated with approximate solutions

Statement of learning outcomes

Learners will be able to:

1. Carry out the FEA steps for modelling of composite materials and structures
2. Explain why FEA normally gives an approximation and list how this approximation may be improved using mesh refinements and/or hierarchal shape functions
3. Explain how to choose an appropriate element type for a composite material, the rules for connecting different element types together, and why restrictions on element shape apply
4. Working in teams, given a problem in stress analysis or heat transfer in composites, build a representative FEA model using the ABAQUS Software, solve for the steady-state stresses or temperatures including checks for accuracy, and write a report analysing the results obtained

Methods of teaching	8 lectures Inc. lab classes and demonstrations
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Product Design B
Unit title	Joints, bonded and bolted
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the processes used to join together composite components and structures or to join such structures onto metallic or other non-composite structures from a manufacturing and outline stress analysis perspective.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Basics of adhesion
2. Advantages of bonded joints
1. Disadvantages of bonded joints
2. Surface energy and wetting
3. Adhesive types
4. Bonded joint configurations
5. Deformations and stress distributions
6. The importance of peel stresses
7. Failure modes and surface preparation
8. Estimation of joint strength
9. Fatigue and environmental effects
10. Basics of mechanically fastened joints
11. Advantages of bolted joints
12. Disadvantages of bolted joints
13. Bolted joint configurations
14. Design considerations
15. Stresses around a pin joint
16. Bolted joint failure modes
17. Target failure mode
18. Joint strength versus lay-up
19. Fatigue issues
20. Multifastener joints
21. Tolerances and thermal effects
22. Bearing/bypass effects

Statement of unit aims

The aims of this unit are to:

1. Provide learners with an overview of jointing techniques for composite structures
2. Identify the major features of bonding and bolting structures, distinguishing the advantages and disadvantages of each approach
3. Enable learners to decide which approach to be used in specific design cases

Statement of learning outcomes

Learners will be able to:

1. Identify when bonding or bolting is the appropriate solution
2. Carry out an outline stress analysis to estimate the load bearing capacity of the joint
3. Identify likely failure modes

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

Taught block title	PRODUCT DESIGN B
Unit title	Damage Tolerance
Level (Credit points)	
Unit director	Martyn Jones/ Prof Richard Day

Unit description

This unit forms part of the Masters level Composites Curriculum. Students who study this module will understand the key points of damage tolerance and how the design of a composite can ensure safety critical structures can survive after failure.

Core subjects to be covered

1. Damage resistance and damage tolerance
2. Types/Sources of damage
3. Design processes to ensure durability
4. Structural categorisation
5. Sandwich impact damage
6. Influence of manufacturing defects
7. Fatigue in composites
8. Visual inspection guidelines and methods
9. Non-destructive testing
10. Mechanical testing processes
11. Structural reliability, A Basis and B Basis
12. Standards and procedures
13. Repair methods after damage
14. Use of Finite Element Analysis (FEA) to predict damaged and fracture.

Statement of unit aims

The aims of this unit are to:

1. Develop a systematic understanding of damage tolerance and its implication in structural design with composites
2. Develop a critical understanding of impact damage and environmental effects on a composite structure.
3. Assess the implications of component design, material section, transition zones and ply stacking sequences.
4. Allow learners to select appropriate inspection and testing methods for damage

Statement of learning outcomes

Learners will be able to:

1. Have a systematic understanding of the effect of impact and environmental effects on composite components and its strength
2. Develop a practical knowledge of standards related to damage tolerance and reliability, and how inspection, testing a repair can be undertaken safely
3. Critically analyse designs for damage tolerance to include, matrix and fibre materials, fibre architecture, monolithic/sandwich structures, and ply drop off zones

Methods of teaching	4 lectures, 2 lab sessions and demonstrations, 2 computer sessions
Assessment details if required	100% assignment (2 assessments worth 50/50)
Timetable information	(4 days)

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes A
Unit title	Reinforcement manipulation and preforming
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the handling and manipulation of broad goods reinforcements both dry and preimpregnated and to the requirements for the production of complex preforms for subsequent further processing.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Handling and manipulating rolls of reinforcement
2. Cutting methods, manual and automated
3. Nesting cutting patterns to minimise waste
4. Pick and place end effectors for handling reinforcements
5. Backing film removal for preimpregnated reinforcements
6. Deformation modes for reinforcements
7. Forming reinforcements to required geometries, draping versus darting
8. Manual lay-up of preimpregnated reinforcements
9. Best practice in the design of lay-up strategies
10. Developing Manufacturing Instruction Sheets for manual lay-up
11. Automation of manufacture using preimpregnated broad goods
12. Preforming of dry/bound reinforcements
13. Binders
14. Preform equipment design
15. Defining a set of preforms to generate a required complex geometry
16. Case studies

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of reinforcement handling and manipulation processes
2. Demonstrate the means by which reinforcements may be cut, transferred, stacked and otherwise handled
3. Provide learners with the understanding to develop reinforcement handling and preforming approaches

Statement of learning outcomes

Learners will be able to:

1. Identify appropriate means of preparing reinforcement packs for subsequent processing
2. Identify the strengths and limitations of different approaches
3. Support the design of preforming equipment and processes

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes A
Unit title	Contact moulding
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units "Introduction to Composites", "Composites Constituents" and to provide Learners with a good understanding of the characteristics of open mould process, e.g. spray-up and hand lamination.

Core subjects to be covered

1. Resins and reinforcements
2. Health and Safety, Occupational Exposure Standards
3. Mould tools: design, materials.
4. Gel-coating
5. Spray-up
6. Hand lamination
7. Centrifugal casting
8. Practical issues: void minimisation, "consolidation" rollers, thixotropy
9. Limitations of contact moulding

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the basic composite manufacturing processes.
2. Provide Learners with an overview of the (few) advantages and (many) constraints when producing composites by contact moulding.
3. Give Learners the tools to select materials to achieve the best practical result given the process limitations.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the low-cost processes for composites manufacture
2. Establish an appropriate working procedure for manufacture low-performance composites.
3. Understand the issues constraining the achievement of high-performance composites bu contact moulding.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes A
Unit title	Prepreg processes, vacuum bag
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces learners to the processes used in the manufacture of composites structures from preimpregnated reinforcements in single sided tools. Both autoclave moulding ad out of autoclave processing routes will be considered. Cored sandwich panels are a very common form of composites structure and are addressed in this unit.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Basics of single sided tooling processes
2. Bleeders, breathers and vacuum bags
3. Tooling features
4. Autoclaves and ovens
5. Autoclave tooling
6. Heat transfer issues
7. The development of contact between the prepreg and the tool
8. Consolidation issues
9. Cure scheduling
10. Sandwich panel basics
11. Honeycomb properties
12. Foam core properties
13. Selecting the right foam or honeycomb core
14. Splicing and filleting adhesives
15. Machining cores
16. Defects in honeycomb cored sandwich panels

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of prepreg moulding techniques, including their advantages and disadvantages
2. Provide learners with an understanding of the range of processes available, the features of each process and how those features impact on the design of materials to be processed by those processes
3. Introduce learners to the manufacture of sandwich panels

Statement of learning outcomes

Learners will be able to:

1. Select appropriate materials and processes to manufacture composite structures in single sided tools
2. Accommodate the characteristics of those processes in the design of composite structures
3. Identify where process control is needed to ensure component quality

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum

Taught block title	Manufacturing Processes A
Unit title	4.4 Prepreg and SMC processes/compression moulding
Level (Credit points)	M (2)
Unit director	Andrew Mills

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the well-established manufacturing process of matched tool compression moulding. The process is the predominant technique for high rate, thermoset matrix composite materials. Both pre-impregnated continuous reinforcement and chopped fibre moulding compound variants are covered

Core subjects to be covered

Prepreg

1. The process – Why it's done and main benefits
2. Process steps and illustrations
3. Lay-up b. Diaphragm forming option c. Pressing
4. Process features and benefits
5. Surface finish, snap cure systems, tooling & equipment, thickness tailoring issue
6. Application examples
   Nissan GTR boot, Alfa Guilia bonnet
7. Process and quality difficulties
8. Part design guidelines for the process

SMC / CFSMC / CFMC

9. The process – Why it's done and main benefits
10. Process steps and illustrations
11. Charge placement b. Pressing
12. Process features and benefits
13. Surface finish, insert incorporation, tooling
14. Application examples
    BMW 7 Series C pillar, Lamborghini Huracan wing
15. Process variants – Prepreg CFSMC co-curing (hybrid moulding)
16. Process and quality difficulties
17. Part design guidelines for the process

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the compression moulding processes
2. Identify the advantages and limitations of the processes
3. Identify process and quality difficulties
4. Provide the learners with information to support the design of composite products to be manufactured by compression moulding
5. Provide design advice applicable to the processes

Statement of learning outcomes

Learners will be able to:

1. Understand compression moulding process techniques
2. Understand the advantages and disadvantages of compression moulding
3. Understand some of the issues involved in the selection and design of composites for manufacture by compression moulding

Methods of teaching	4 lectures, 1 lab class and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes A
Unit title	Resin Transfer Moulding
Level (Credit points)	M (2)
Unit director	Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the manufacture of fibre-reinforced composites by rigid tool resin transfer moulding processes.

Core subjects to be covered

1. History and development of RTM
2. Advantages and disadvantages of RTM
3. RTM theory and simulation
4. Choosing materials for RTM
5. Reinforcement manipulation and preforming
6. RTM mould tool design
7. Production engineering requirements
8. Component design for RTM
9. Thick section RTM
10. Monitoring and control of RTM
11. Troubleshooting RTM processing problems
12. Suggestions for good practice in the design and development of RTM components
13. Costing for RTM
14. Quality considerations in RTM
15. Case studies
16. Future development directions

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the development of the Resin Transfer Moulding process, its advantages and disadvantages
2. Provide Learners with an overview of how parts can be designed for RTM and successfully manufactured
3. Give Learners the tools to operate RTM processes in a production environment.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the capabilities of the Resin Transfer Moulding processes
2. Design or make recommendations for the design of products to be manufactured by RTM.
3. Understand the operation of the RTM process in a production environment.

Methods of teaching	7 lectures and associated demonstrations and exercises, including practical
Assessment details if required	Written assignment
Timetable information	2 days of teaching in a block.

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes A
Unit title	Resin infusion processes
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the manufacture of fibre-reinforced composites by infusion processes.

Core subjects to be covered

1. The RTM- infusion- prepreg continuum.
2. Vacuum integrity of mould tools.
3. Process and consumable materials.
4. Reusable "consumables".
5. RIFT1: in-plane flow parallel to the layers of reinforcement.
6. RIFT2: through-plane flow from a flow medium or scored core (SCRIMP/VARTM).
7. RIFT3: resin film infusion (RFI).
8. RIFT4: partially pre-impregnated materials.
9. Double diaphragm infusion techniques.
10. In-mould gel-coating.
11. Infusion of large structures.
12. Process monitoring and control.
13. Simulation software (LIMS/PAM-RTM/Polyworx)

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the continuum of processes from RTM through infusion to prepregging.
2. Provide Learners with an overview of the specific variations of infusion processes.
3. Give Learners the tools to optimise infusion manufacturing processes.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the range of infusion manufacturing processes
2. Establish an appropriate manufacturing system for infusion of different composites aligned to the specific requirements of the consumer.
3. Understand the issues constraining the use of infusion to meet specific performance parameters.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes B
Unit title	AFP and ATL
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to two important automated reinforcement collation processes Automated Fibre Placement and Automated Tape Laying. The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. History and development of the ATL and AFP processes
2. Current status of processes
3. Basic principles of operation, gantry vs robot designs
4. Productivity issues
5. Accuracy and control issues
6. Temperature control and heating strategies
7. Thermoset matrix processing
8. Thermoplastic matrix processing
9. The lay-up head design and operational issues
10. Geometric conformance
11. Impacts on cured ply thickness and as-laid quality
12. Monitoring and control
13. Advantages and limitations of AFP & ATL
14. Simulation of AFP & ATL
15. Steering effects and tack
16. Dry Fibre AFP issues
17. Tailored blanks and post-forming
18. Principles of part design for AFP & ATL
19. Software tools
20. Integrating AFP & ATL into a manufacturing plant
21. Costing for AFP & ATL
22. Development areas and future research

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the AFP & ATL reinforcement collation processes
2. Identify the advantages and limitations of the processes
3. Identify quality limiting aspects of the processes
4. Provide the learners with information to support the design of composite products to be manufactured by AFP & ATL.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the advantages and disadvantages of the AFP & ATL processes for reinforcement collation
2. Understand the features of the AFP & ATL processes and how these may be simulated
3. Understand some of the issues and methodologies involved in the selection and design of composites for manufacture by AFP & ATL

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Rapid Prototyping (RP) and Additive Manufacture (AM)
Level (Credit points)	H (2)
Unit director	Dr Jasper Graham-Jones

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the potential routes to manufacture of polymer and composite components by Rapid Prototyping (RP)/Additive Manufacture (AM).

Core subjects to be covered

1. Materials selection.
2. Fused Deposition Modelling (FDM).
3. Selective Laser Melting (SLM)/ Selective Laser Sintering (SLS).
4. Liquid binding
5. Stereolithography (SL)
6. Laminated Object Manufacturing (LOM).
7. Novel emerging methods.
8. Particle, whisker and fibre-reinforcement
9. Open access CAD/public access.
10. Acceptable quality/tolerances/permitted defects.
11. Customisation and complexity.
12. Supports, hinges and origami.
13. 4D-printing (shape shifting post-process).
14. Process monitoring and control.
15. Process simulation and design software

Statement of unit aims

The aims of this unit are to:

1. Give Learners an overview of the variety of processes available within the generic descriptions Rapid Prototyping (RP) and Additive Manufacture (AM).
2. Provide Learners with an understanding of the specific variations of RP and AM processes.
3. Give Learners the tools to analyse RP and AM to optimise processes.

Statement of learning outcomes

Learners will be able to:

1. Choose appropriate processes from the range of Rapid Prototyping (RP) and Additive Manufacture (AM) processes available.
2. Specify the systems required for manufacture by RP or AM for different composites aligned to the specific requirements of the consumer.
3. Understand the issues that constrain the optimisation of RP or AM processes.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes B
Unit title	Filament winding and pultrusion
Level (Credit points)	M (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to two important automated processes, Filament winding and Pultrusion. The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. The historical development of filament winding (FW)
2. Winding pattern (hoop, helical or polar), geodesic path, Clairaut angle, and friction
3. Software for filament winding design
4. Basic principles of operation: increasing degrees of freedom
5. Fibre feed arrangements and filament wetting
6. Control, productivity and accuracy issues
7. Thermoset matrix FW
8. Thermoplastic matrix FW
9. Influence of process parameters on quality and conformance to design.
10. The history and development of pultrusion
11. Principles of part design for pultrusion
12. Fibre preform management, and wetting, before die entry
13. Consolidation and cure in the die
14. Haul-off and section cutting
15. Pulforming, pulwinding and pulbraiding
16. Quality and costing for FW & pultrusion
17. Development areas and future research

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the filament winding and pultrusion processes
2. Provide the learners with information to support the design of composite products to be manufactured by filament winding and pultrusion.
3. Identify the advantages and limitations of the processes
4. Identify quality limiting aspects of the processes

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the advantages and disadvantages of the filament winding or pultrusion processes for composites production
2. Understand the features of the filament winding or pultrusion processes and how these may be simulated
3. Understand some of the issues and methodologies involved in the selection and design of composites for manufacture by filament winding or pultrusion processes

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes B
Unit title	Thermoplastic matrix processes
Level (Credit points)	M (2)
Unit director	Description produced by Sean Cooper, NCC

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units “Polymeric matrices” “Joints; bolted and bonded” and aims to provide Learners with a good understanding of the characteristics of thermoplastic matrix composite processes, e.g. stamp-forming, compression moulding and injection/ overmoulding. The unit also introduces joining of thermoplastic composites by common welding practices.

Core subjects to be covered

1. Advantages and disadvantages of thermoplastic matrix composites
2. Introduction to stamp forming
3. Stamping tool and shuttle system design
4. Typical forming defects, e.g wrinkling, warp
5. Introduction to compression moulding
6. Typical defects voids, e.g. cracking, sinkmarks
7. Introduction to Injection/overmoulding
8. Tool design aspects, cores, hot runner, material transfer end-of-arm tooling
9. Typical defects, e.g. sink marks, short shot, warpage, moisture
10. Introduction to thermoplastic welding, polymer chain reptation/diffusion and interface model
11. Resistance welding process
12. Ultrasonic welding process
13. Induction welding process
14. Thermoplastic composites manufacturing and joining case study examples (various automotive, rail, aerospace)

Statement of unit aims

The aims of this unit are to:

1. Introduce learners to thermoplastic matrix processes including thermoforming, compression moulding and injection/overmoulding
2. Give Learners an understanding of thermoplastic composite welding processes including resistance, ultrasonic and induction
3. Provide industry/research examples of the use of thermoplastic composites across aerospace, rail, automotive and other sectors

Statement of learning outcomes

Learners will be able to:

1. Discuss the advantages and disadvantages of thermoplastic composites
2. Identify and explain some specific thermoplastic matrix manufacturing processes
3. Understand polymer reptation & welding as a difference to bonded or bolted joints
4. Identify and explain specific thermoplastic matrix welding processes
5. Use appropriate skills for identifying and resolving typical defects for any of the manufacturing or welding processes discussed above

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum

Taught block title	Manufacturing Processes B
Unit title	5.5 Process Automation
Level (Credit points)	M (2)
Unit director	Andrew Mills

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to automated processing, a rapidly developing area for high rate composite component manufacturing. The unit covers six areas of manufacturing; Material lay-up, reinforcement preforming, robotic handling and part trimming/machining, assembly by bonding and assembly by fastening.

Core subjects to be covered

1. Automation benefits – speed, labour cost, repeatability, QA
2. Process description, machines, process steps, benefits, challenges for each or the below:

1. Lay up

Prepreg – ATL, Tow placement (Fiber placement) FP, pick and place, table rolling.
Dry fabrics & tapes – Tape laminating, woven and NCF pick and place
Dry tow – Filament winding
Application examples – A350 wing skin, A380 rear fuselage, automotive door skin, golf club shaft, wind turbine NCF

2. Preforming

Vacuum, diaphragm, pressing, braiding, chopping/spraying
Application examples – BMW i3, Audi A8 bulkhead, Huracan A pillar, AM Vanquish wing

3. Closed moulding robot handling

RTM preforming loading, resin injection cell
Application example – BMW 3 series roof

4. Trimming and machining – ultrasonic and water jet cutting

Application example – BMW i3

5. Assembly by bonding

Application example - BMW i3, BMC bike frame

6. Assembly by fastening

Application example – Airbus A400M

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the uses of automation in composites moulding processes
2. Identify process difficulties
3. Provide the learners with information to support the design of composite products to be manufactured using automation
4. Provide design advice applicable to the processes

Statement of learning outcomes

Learners will be able to:

1. Understand the application of automation for moulding processes
2. Understand the benefits and restraints for the use of process automation
3. Understand some of the issues involved in the selection and design of composites for manufacture using automation

Methods of teaching	5 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Processes B
Unit title	Processes for ceramic matrix composites (CMC) and metal matrix composites (MMC)
Level (Credit points)	M (2)
Unit director	Kevin Potter and John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with composites with a general introduction to the processes that can be used in the manufacture of components and structures using ceramic matrix composites and metal matrix composites.

Core subjects to be covered

1. Background and history
2. CMC- Solid phase powder metallurgy
3. CMC- Solid phase slip casting
4. CMC- Microwave sintering
5. CMC- Reaction bonding
6. CMC- Sol-gel processes
7. CMC- Liquid phase infiltration pyrolysis
8. CMC- Chemical/physical vapour deposition/infiltration
9. CMC- Machining processes
10. Particulate MMC processes – Stir casting
11. Particulate MMC processes – Squeeze casting
12. Particulate MMC processes – Powder metallurgy approaches
13. Particulate MMC processes – nanoscale reinforcements
14. Fibre/whisker reinforced MMC
15. MMC- Fibre reinforced metal injection moulding
16. MMC- Fibre manipulation and preform preparation
17. MMC- Preform infiltration
18. MMC- Fibre reinforced metal Solid state processing
19. MMC- In situ synthesis of reinforced metals
20. MMC- Process comparison and process selection
21. Machining processes for MMC
22. Carbon/Carbon composites: - resin impregnation followed by pyrolysis
23. C/C: Chemical Vapour Deposition from hydrocarbon precursor gas

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the processes for the manufacture of components and structures by routes to ceramic matrix composites
2. Provide Learners with an overview of the processes for the manufacture of components and structures by routes to metal matrix composites
3. Provide learners with an understanding of the capabilities and limitations of the available processes that can be applied in a part design environment

Statement of learning outcomes

Learners will be able to:

1. Identify appropriate processes for the manufacture of components in ceramic and metal matrix composites
2. Understand the ways in which process selection impacts on costs and performance of ceramic and metal matrix composites
3. Understand how to introduce the potential for ceramic and metal matrix composites in a design environment

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations A
Unit title	Production costing
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the concepts of production costing and supports them to be confident in the use of costing approaches.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

18. Company structures
19. Cost centres
20. Direct and indirect costs
21. Recurring and non-recurring costs
22. Costing methodologies
23. Job costing
24. Standard costing
25. Activity based costing
26. Direct costing
27. Parametric costing
28. Target (should cost) costing
29. Make or Buy decisions
30. Supply chain issues
31. Manufacturing equipment procurement
32. Factory space and facilities procurement
33. Delivery cost estimation
34. Introduction to Life Cycle costing
35. Commercially available cost modelling software
36. The Virtual Composites Company approach

Statement of unit aims

The aims of this unit are to:

5. Provide Learners with an overview of costing for composite products that are to be manufactured in a production environment.
6. Demonstrate how costs are built up in a production environment and how investment decisions can be made
7. Provide learners with an opportunity to use software tools to carry out trade studies

Statement of learning outcomes

Learners will be able to:

4. Identify the right approaches to product costing and understand their strengths and weaknesses
5. Identify the information required to carry out an effective costing and how such information can be obtained
6. Carry out simple costing using a spreadsheet model

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations A
Unit title	Process design
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the need for a controlled structure for process design in composites to achieve reliable production. It identifies the targets for process control and the difficulties inherent in meeting those targets. It provides a methodology whereby robust decisions on process design can be made.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. The need for process design
2. Identifying expected part thickness
3. Factors impacting mean cured ply thickness
4. Reinforcement consolidation curves
5. Identifying the correct pressure cycle
6. Identifying limiting process parameters for acceptable quality on flat laminates
7. The effect of resin sinks in prepreg mouldings
8. The impact of bridging in internal radii
9. Consolidation effects on external radii
10. Cure scheduling
11. Maximum and Minimum cure temperatures
12. Heat transfer effects
13. Temperature distribution
14. Exotherm effects
15. Cool down and demould temperature
16. Postcure
17. Cure scheduling

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the need for a clearly defined process design to deliver a controlled production
2. Demonstrate to learners where control is needed and provide the tools that can be used in process design
3. Clarify the role of process design within a product design framework

Statement of learning outcomes

Learners will be able to:

1. Identify those factors that must be controlled in a composites manufacturing environment
2. Carry out estimates of the impact of poorly controlled processes
3. Integrate process and product design

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Manufacturing Operations A
Unit title	Process modelling
Level (Credit points)	
Unit director	Alex Skordos

Unit description

This unit deals with the simulation of composites manufacturing covering the main processing steps and the use of simulation for process design.

Core subjects to be covered

1. Drape modelling
2. Forming simulation
3. Filling simulation
4. Consolidation simulation
5. Cure simulation
6. Modelling of residual stress development
7. Model validation
8. Process optimisation
9. Variability and stochastic simulation

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with knowledge of the main methodologies for simulating composites manufacturing
2. Present simulation in the context of practical process design
3. Provide an understanding of the capabilities of simulation tools

Statement of learning outcomes

Learners will be able to:

1. Understand the approaches used to translate relevant physical phenomena to models
2. Practise the use of simulation tools covering aspects of composites manufacturing simulation
3. Understand the role of modelling in the development and design of processing methods

Methods of teaching	9 lectures, 9 computer based tutorials
Assessment details if required	Written assessment (100%)
Timetable information	3 days teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations A
Unit title	Process monitoring
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites", "Composites Constituents" to provide Learners with a good understanding of the quality systems appropriate to composites manufacture.

Core subjects to be covered

1. Quality Management Systems standards (ISO 9000)
2. Environmental Management Systems standards (ISO 14000)
3. Occupational Health and Safety Management standards (OHSAS 18000)
4. Project planning. Technology Readiness Levels (TRL).
5. Problem Solving Techniques
6. Quality Circles. Kaizen. Poka-Yoke.
7. Temperature, Pressure, and calibration
8. Viscosity, flow rate, and flow front position
9. Degree-of-Cure: dielectrometry, IR/Raman, ultrasonics and mechanical impedance analysis
10. Statistical Process Control. Six Sigma.
11. QFD and PFMECA.
12. Process control: PID, ANN, FL, GA
13. Big Data & Industry 4.0

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of composite manufacturing quality systems.
2. Provide Learners with an overview of the resources available for problem identification and resolution.
3. Give Learners the tools to run an effective and efficient manufacturing system.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of quality systems for composites manufacture
2. Establish appropriate procedures for process control.
3. Understand the issues which enable optimisation of processes.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations A
Unit title	Process planning
Level (Credit points)	M (2)
Unit director	Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units “Introduction to Composites” and “Manufacturing of composite products” to provide Learners with a good understanding of the principles of process planning in a composites manufacturing facility. The baseline assumption is that the activity is being carried out in a quality critical/aerospace environment.

Core subjects to be covered

1. Defining the design intent in detail to support all subsequent steps
2. Identifying manufacturing data capture and data management requirements
3. Defining the manufacturing process flow, Bill of Materials and Work Breakdown Structure
4. Identifying all materials with associated purchase specifications and storage requirements
5. Tracking life-limited materials
6. Part marking and traceability
7. Identifying all jig and tool requirements
8. Identifying all equipment requirements (e.g. ply cutter, AFP, autoclave or C-scan)
9. Identifying each step in a detailed manufacturing instruction document
10. Materials and equipment capacity and batch scheduling requirements
11. Commercial process planning models
12. ERP systems
13. Interfacing with Quality and MRB systems
14. Tracking design changes
15. Tracking and scheduling rework or repair
16. Integrating process planning into automated composites manufacturing facilities
17. Process planning in a high-volume manufacturing environment
18. Recent developments in process planning

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the issues associated with the development of process planning and documentation for new composite product manufacture
2. Provide Learners with an overview of how to develop process planning and the associated documentation to control the manufacture of composite structures

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the process planning procedures
2. Work as part of a team planning the introduction of composites manufacturing processes

Methods of teaching	6 lectures and associated group exercises, including industrial examples
Assessment details if required	Written assignment
Timetable information	2 days of teaching in a block.

COMPOSITES CURRICULUM - Unit Information

Taught block title	MANUFACTURING OPERATIONS A
Unit title	Tooling Design and Manufacture
Level (Credit points)	
Unit director	Martyn Jones/ Prof Richard Day

Unit description

This unit forms part of the Masters level Composites Curriculum. Its purpose is to describe and detail the materials, process and requirements in designing tooling for the manufacture of composite components.

Core subjects to be covered

1. Overview of different manufacturing processes and the challenges in designing tooling for these applications.
2. Tooling systems for prepreg and fibre manufacture
3. Material selection in tooling design
4. Thermal endurance requirements
5. Conventional mould design
6. Advanced tooling design for pultrusion, filament winding etc
7. Consumables used for tooling materials with reference to release agents
8. Mechanisms in composite distortion during cure
9. Design to compensate for spring back of curved composites
10. Tolerance build up
11. Maintenance of tooling for composite components
12. Mould design using CAD (Catia Composites workbench)
13. Sustainable tooling design

Statement of unit aims

The aims of this unit are to:

1. Allow learnings to critically assess the tooling material requirements based on material and cure properties
2. Develop a deep understanding of the phenomena that causes cure distortion and how tools are designed to compensate for this.
3. Understand the different manufacturing process and the tooling required for each method
4. How to use and maintain composite tooling correctly and sustainably.

Statement of learning outcomes

Learners will be able to:

1. Have a systematic understanding of how to design tooling based on the manufacturing processes utilised
2. Critically evaluate how tooling can contribute to the form and geometry of the final component after cure
3. Develop a practical knowledge of tooling maintenance and operation process

Methods of teaching	6 lectures, 1 lab classes and demonstrations, 1 CAD session and1 class exercise
Assessment details if required	100% design task assessment
Timetable information	3 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Manufacturing Operations B
Unit title	Joining & Assembly
Level (Credit points)	
Unit director	Dr. Hamed Yazdani Nezhad

Unit description

The unit provides a knowledge-based, industrial-oriented taught module on assembly and joining of high-performance composite structures, via providing theoretical framework and common practices for composite joints and assemblies.

Core subjects to be covered

1. Introduction to composite structural Integrity
2. Best Practices in Bonding, Bolting and Assembly Approaches
3. Thermoplastic welding
4. Material removal and surface preparation
5. Mechanical performance of bolted and bonded assemblies
6. Stress distribution in adhesively bonded composite joints
7. Load path eccentricity in composite joints
8. Plastic behaviour of composite joints
9. Adhesive Bond Damage Tolerance and Failure Assessment
10. Fatigue failure in bolted and bonded joints
11. Bond failure in environmental conditions
12. Process-induced Defects in Composite fastening and bonding
13. NDT of composite assemblies
14. Stresses in fasteners and bonds
15. Strength variation along degrading interface
16. Correlation between defect type and failure mode
17. Cohesion failures
18. Adhesion failures
19. Mixed-mode failures
20. Mechanism of interfacial degradation
21. Stress in doubler bonded assemblies
22. Adhesive failure by shear or peel
23. Design of adhesively bonded composite assemblies

Statement of unit aims

The aims of this unit are to:

1. Provide intense knowledge-based industrial oriented learning sessions on composite integration and joining
2. Provide deterioration mechanisms occurring in processing and assembly of composite materials and structures.

Statement of learning outcomes

Learners will be able to:

1. Appreciate a variety of integration, repair and joining procedures in composite structures from fastening, thermoset adhesive bonding to thermoplastic welding
2. Understand deterioration mechanisms occurring in processing and assembly of composite materials and structures.
3. Learn about adhesive bond damage tolerance and failure assessment procedures.

Methods of teaching	9 lectures Inc. demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations B
Unit title	Factory design and layout
Level (Credit points)	M (2)
Unit director	Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units "Introduction to Composites" and "Manufacturing of composite products" to provide Learners with a good understanding of the principles behind the design, development and layout of factories to manufacture composite products. The unit starts from the assumption of the need to build a new facility for a single product line.

Core subjects to be covered

1. Background to building factories in the UK
2. Investment planning - build to final scale or with scale-up options etc
3. Identifying the detailed production process steps
4. Identifying the associated production process equipment
5. Identifying ancillary process equipment
6. Developing the equipment specifications identifying any special build issues (pits, craneage, air conditioning, clean rooms, nitrogen plants and hard floors etc)
7. What-if scenario planning to identify critical equipment utilisation and similar assumptions – including a range of % right first-time assumptions
8. Mapping production flows – simulating the factory to permit virtual debottlenecking
9. Developing baseline assumptions case to set commissioning targets
10. Identifying space requirements – equipment footprint
11. Identifying space requirements – working area, circulation area, storage and office space.
12. Estimating factory build costs
13. Estimating factory build time
14. Procurement issues
15. Equipment installation and commissioning
16. Initiating production and data collection to check against assumptions and map value streams.
17. Factory efficiency improvement processes
18. Modifying or repurposing existing factories to change product lines or processes
19. Conclusions and lessons learned

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the development of the issues associated with the development of new composites manufacturing facilities
2. Provide Learners with an overview of how to design, procure and commission a factory for composites manufacture

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the factory design procurement and set-up process
2. Work as part of a team developing and delivering new composites manufacturing facilities

Methods of teaching	6 lectures and associated group exercises
Assessment details if required	Written assignment
Timetable information	2 days of teaching in a block.

Composites Curriculum – Unit information

Taught block title	Manufacturing Operation B
Unit title	**Agile, Lean, Six Sigma and similar methods**
Level (Credit points)	M(2)
Unit director	Initial draft by John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces learners to the administration and quality systems that potentially make an adequate organisation into a best-in-sector operation. The course should be delivered with a focus on exemplar case studies from within the composites industry. The module complements Manufacturing Operations A/Process Monitoring.

Core subjects to be covered

1. World-Class organisational culture
2. Quality management and the gurus
3. Customer needs and requirements
4. Houses of Quality (QFD),
5. SPC, PFMECA, Kaizen, Poka-Yoke
6. Computer Aided Production Management
7. Six Sigma/DMAIC
8. Process capability, variability and yield
9. Empowering employees as decision makers
10. Appropriate supplier/partner relationships
11. Supply chain management and risk
12. Effective IT, data integrity, ERP
13. Change management (or failures)
14. Lean/agile transformations
15. Integrate ISO9000/14000/27000 & OHSAS18000

Statement of unit aims

The aims of this unit are to:

1. Provide learners with a broad overview of systems which enable sustainable commercial business.
2. Identify techniques, and case studies, that can be implemented in industry.
3. Provide a framework for critical analysis of composite manufacturing operations.
4. Identify support systems for improvement of manufacturing operations.

Statement of learning outcomes

Learners will be able to:

1. Clearly describe quality management systems in the context of composites manufacture.
2. Understand the routes to optimisation of composites manufacturing processes
3. Undertake critical analysis of failing commercial systems.

Methods of teaching	7 lectures, 2 tutorials, 1 group exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations B
Unit title	Tolerancing, variability and defects
Level (Credit points)	M (2)
Unit director	Professor Kevin Potter

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the factors influencing the geometrical tolerances in composites manufacture, including the impact of variability in both materials and processes. The unit also considers the origins and impacts of a wide range of defects.

The course will be delivered from processing science and manufacturing engineering perspectives.

Core subjects to be covered

1. Variability in incoming materials
2. Materials specifications and control
3. Thickness variability in bag or "floating tool" moulding
4. Geometric fidelity
5. Spring-in thermoelastic effects
6. Spring-in non-thermoelastic effects
7. What is a defect?
8. Defect Taxonomy
9. Acceptance criteria
10. Rework, repair and concessions
11. Cosmetic errors
12. Delaminations
13. Voidage
14. Fibre waviness and wrinkling
15. Cure related defects
16. Machining defects
17. Defect root cause investigations

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the factors influencing geometrical tolerances in composites mouldings
2. Provide an overview of the sources of variability in materials and processes and how those variabilities manifest through geometrical fidelity
3. Consider the range of potential defects, their possible impacts and the opportunities for mitigation in the process

Statement of learning outcomes

Learners will be able to:

1. Identify sources of variability in composite components and manufacturing processes
2. Generate designs which limit or control variability
3. Identify the potential for defect generation in component designs

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Core Block
Unit title	Machining composites
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the capabilities and limitations of cutting, drilling and other processes for reshaping laminates.

Core subjects to be covered

1. Health and Safety considerations (effects of dust on the human body, how to work safely)
2. Fixturing, datum control and clamping
3. Material removal techniques (cutting, sawing, drilling, turning, milling, routing, lapping, grinding, etc.)
4. Traditional tool materials (steel, WC,and diamond/BN) and geometry
5. (Abrasive) water jet machining
6. Ultrasonic machining
7. Electrochemical and electrical discharge machining
8. Laser machining
9. (Photo-)chemical machining
10. Plasma arc methods
11. Special considerations for aramids and natural fibre composites
12. Machining damage (delamination, burr, back-up plates, coolant),
13. Hole quality (cylindricity, diameter error)
14. Cutting forces
15. Process modelling, optimisation and control
16. Condition monitoring and non-destructive evaluation
17. Dimensional inspection
18. Economic and environmental considerations

Statement of unit aims

The aims of this unit are to:

1. Give learners an understanding of the options available for removal of material from laminates
2. Provide Learners with an overview of the capabilities and limitations of machining in the context of fibre reinforced composites
3. Give learners the tools to make the most appropriate choice of machining process for a specific application
4. Provide the learners with an understanding of process issues required to machine composites with minimal/zero damage

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the capabilities and limitations of machining for composites
2. Establish which machining processes are the most appropriate choice for a specific application
3. Understand the process issues in machining a wide selection of composites

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Manufacturing Operations B
Unit title	Surface finishing and painting
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the capabilities and limitations of coating systems.

Core subjects to be covered

1. Coating laminates, or laminating-to-coatings
2. Surface preparation
3. Paint formulation and characterisation
4. Paint application
5. Gel-coats formulation and characterisation
6. Open mould gel-coating
7. In-mould gel-coating
8. Metallisation of polymeric surfaces
9. Classification of defects in coatings: to include pinholes, print-through
10. Measurement of quality for surface finishes
11. Functional coatings, including self-cleaning surfaces and anti-fouling systems
12. Removal, repair and disposal of coatings
13. Cost and environmental issues

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the range of coating materials and process options
2. Provide Learners with an overview of the capabilities and limitations of coating systems
3. Give Learners the tools to determine and appropriate coating system for a specific application
4. Provide the Learners with an understanding of process issues constraining the surface finish of composites

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the capabilities and limitations of coating systems
2. Establish an appropriate coating system for a specific application
3. Understanding of process issues constraining the surface finish on composites

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

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COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Mechanical properties and testing - anisotropic elasticity
Level (Credit points)	H (2)
Unit director	Dr. Nuri Ersoy

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with composites with a general introduction to the basic mechanical properties and how they can be obtained through standardized testing.

Core subjects to be covered

1. Orthotropic materials
2. Transverse isotropy
3. Engineering properties of orthotropic and transversely isotropic materials
4. Testing standards for Mechanical Properties of Composites
5. Test Specimen Preparation, Strain, and Deformation
6. Measurement Devices, and Testing Machines
7. Specimen Preparation and Tab Bonding
8. Strain and Displacement Measurements
9. Testing Machines
10. Tension Test Procedure (ASTM 3039)
11. Compression Test Procedures
    1. IITRI Test Procedure (ASTM D 3410)
    2. ASTM D 695 Test Procedure
12. CLC Test Procedure (ASTM D 6641)Shear Testing
    1. Iosipescu Shear Test Method (ASTM D 5379)
    2. Two-Rail Shear Test Method (ASTM D 4255)
    3. Three-Rail Shear Test Method (ASTM D 4255)
    4. [±45]ns Tensile Shear Test Method (ASTM D 3518)
    5. Short Beam Shear Test Method (ASTM D 2344)

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the concepts of isotropy, orthotropy, and transverse isotropy
2. Identify the engineering constants required to define isotropic, orthotropic, and transversely isotropic materials
3. Provide the learners with an understanding of testing machines, measuring devices, and specimen preparation
4. Give learners an understanding of the standardized test methods to measure the engineering properties of composites

Statement of learning outcomes

Learners will be able to:

1. Acquire an understanding of the mechanical properties of unidirectional fibre reinforced composite materials
2. Identify the tests methods required for mechanical characterization of these materials
3. Comprehend how these materials fail under pure tension, compression and shear loading.
4. Have a preliminary consideration of how the properties measured relate to stress and strength analysis of composite laminates

Methods of teaching	5 lectures, 3 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 min assessed presentation (15%)
Timetable information	2 days of teaching in a block

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COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Mechanical properties and testing - static strength, failure modes and failure criteria
Level (Credit points)	H (2)
Unit director	Dr. Nuri Ersoy

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with composites with a general introduction to the basic strength properties, failure modes, and failure criteria.

Core subjects to be covered

1. Revision of properties obtained by tension, compression, and shear testing.
2. Failure modes under tensile, compressive and shear loading.
3. Multiaxial loading and testing
4. Failure Criteria
    1. Maximum Stress Failure Criterion
    2. Maximum Strain Failure Criterion
    3. Tsai-Wu Failure Criterion
    4. Hashin Failure Criterion
5. Factor of Safety

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of the strength properties obtained by tensile, compression, and shear tests
2. Provide Learners with an understanding of the failure modes under tensile, compression, and shear, and multiaxial loading
3. Provide the learners with an understanding of industrially relevant failure criteria
4. Give learners an preliminary idea of how to use the failure criteria for design of composite laminates

Statement of learning outcomes

Learners will be able to:

1. Assess the factor safety under unidirectional loading in tension, compression, or shear
2. Identify the failure modes under tensile, compression, and shear, and multiaxial loading
3. Understand how the stresses and failure modes interact in the case of multiaxial loading
4. Have a preliminary understanding of how the various failure criteria can be utilized in design of composite laminates

Methods of teaching	8 lectures, 1 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Mechanical properties and testing - dynamic and fatigue
Level (Credit points)	H (2)
Unit director	

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units 'Mechanical properties and testing – anisotropic elasticity' and 'Mechanical properties and testing – static strength, failure modes and failure criteria' to provide Learners with a good understanding of the performance of composite systems under dynamic and fatigue loading conditions.

Core subjects to be covered

1. Introduction and definitions
2. Stress and strain controlled loading
3. Fatigue damage development
4. Monitoring fatigue damage
5. Fatigue testing (tension, compression, fully reversed, shear)
6. Fatigue data representation
7. Factors affecting fatigue performance
8. Predicting performance and life under fatigue loads
9. Delamination growth under fatigue
10. Design for fatigue
11. Low and high velocity impact
12. Impact resistance and impact damage tolerance
13. Impact damage development
14. Factors affecting impact performance
15. Impact test methods and residual properties evaluation
16. Performance under high rate dynamic loading
17. High rate equipment and testing methods
18. Basic principles of crashworthiness and energy absorption mechanisms
19. Crashworthiness testing and simulation

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an understanding of the fatigue and dynamic performance of composites
2. Identify the advantages and limitations of these materials under fatigue and dynamic loading conditions
3. Give learners an overview of the testing methodologies for quantifying the performance of these materials

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the range of fatigue and dynamic test methods
2. Understand some of the issues associated with the use of composites under fatigue and dynamic loading conditions
3. Establish appropriate procedures for using experimental data in the design against fatigue loading and impact threats

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Durability
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the deterioration of composite systems over extended exposure to degrading conditions.

Core subjects to be covered

1. Polymer transition temperatures
2. Thermal degradation and fire
3. Moisture diffusion
4. Marine exposure: osmosis and blistering, galvanic corrosion
5. Weathering: electromagnetic and ionising radiation, precipitation and particle erosion
6. Chemical attack: acids, alkalis, solvents
7. Biological exposure: fouling, fungi
8. Mechanical durability: creep, fatigue, impact
9. Environmental stress corrosion interactions
10. Standard methods of test (NPL MAT85)
11. Highly Accelerated Life Testing (HALT)
12. Structural Health Monitoring (SHM)
13. Lifetime prediction

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the limitations of composites arising from degradation mechanisms
2. Provide Learners with an overview of the mechanisms of deterioration of composite performance
3. Give Learners the tools to design commercial structures that will satisfy performance requirements for the whole life cycle

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the mechanisms of deterioration of composites
2. Establish an appropriate composite system for a specific application respecting the operating environment
3. Understand the issues constraining the use of composites in harsh conditions.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Non-structural properties - erosion, wear, electrical and thermal properties
Level (Credit points)	H (2)
Unit director	Stefanos Giannis

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the units under taught block Performance A to provide Learners with a good understanding of non-structural composite material properties and their importance in designing both conventional and multifunctional structures.

Core subjects to be covered

1. Introduction to non-structural properties
2. Applications requiring non-structural properties
3. Solid particle erosion
4. Effect of erosion and abrasion on surface characteristics and performance
5. Measuring the erosion wear rate on composites
6. Electrical conductivity and percolation theory
7. Modelling electrical conductivity
8. Dielectric performance
9. Measuring volume resistivity, dielectric constant, dielectric dissipation and loss factors
10. Electromagnetic Interference Shielding (EMI)
11. Glass Transition Temperature (T*g*)
12. Factors affecting the T*g*
13. Measuring Tg using Dynamic Mechanical Analysis (DMA) and Differential Scanning Calorimetry (DSC)
14. Thermal Conductivity
15. Factors affecting thermal conductivity
16. Thermal Expansion
17. Measuring thermal expansion using Dilatometry and Thermomechanical Analysis
18. Multi-functional composite materials

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an understanding of the erosion, wear, electrical and thermal performance of composites
2. Give learners an overview of the testing methodologies for quantifying the non-structural properties of composites
3. Identify the advantages and limitations of these materials when designing multi-functional structures

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the diverse non-structural properties of composite materials
2. Establish appropriate procedures for quantifying non-structural performance of composites
3. Understand some of the issues and opportunities associated with the use of composites in multi-functional structures

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance A
Unit title	Fire and Post Fire Mechanical Performance of Composites
Level (Credit points)	M (2)
Unit director	Prof Baljinder Kandola

Unit description

This unit forms part of the Masters level Composites Curriculum.

Core subjects to be covered

1. The basics of combustion of polymeric materials
2. Fire performance of composites
3. Methods of imparting fire retardancy to composites,
4. Materials selection or design for fire safe composites
5. Fire testing methodolgies

Statement of unit aims

The aims of this unit are to:

1. To gain an appreciation of the methods used to reduce flammability of composites through an understanding of the underlying processes, and the use of these methods to select appropriate materials in design of composites.
2. To assess various test methods and instruments used for evaluation of fire performance of materials, and important factors to consider in order to achieve a good result
3. To address how improving one type of performance for example flammability can have a detrimental effect on another such as mechanical performance.

Statement of learning outcomes

Learners will be able to:

1. Relate composite formulations to their burning behaviours
2. Understand different methods / techniques for studying burning behaviour of polymeric materials
3. Relate composites' structures and properties to most appropriate design and selections by taking all parameters into account
4. Understand different test methods to evaluate fire and fire retardant performance

Methods of teaching	Lectures/lab classes/demonstrations/class exercises/etc
Assessment details if required	An assignment in the form of the Integrated Learning Package (ILP) will be provided so that participants will be able to complete the work within xx weeks after the start of the module. The ILP consists of two components in which Part 1 examines the candidate's basic understanding of the concept, principles and awareness of the module, Part 2 probes and investigate selected classes of answers which are designed to reflect deep understanding of the subject.
Timetable information	X days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance B
Unit title	Non-Destructive Testing
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the sensors and systems appropriate to non-destructive testing of composites, for condition monitoring (CM), structural health monitoring (SHM) and in-service inspection, during processing and service, or for failure analysis.

Core subjects to be covered

1. Initial inspection, monitoring in-service (CM/SHM) or failure analysis.
2. Manufacturing defects and service damage
3. Probability of detection.
4. (A) Electromagnetic spectrum; radiography, UV, visible, IR, thermography, THz, microwave, eddy-current, dielectric, electric and magnetic.
5. Synchrotron/x-ray/isotope imaging
6. White light and laser technologies
7. Thermography
8. Dielectrometry/moisture meters
9. (B) Chemical spectroscopy: NMR, Raman, NIR
10. (C) Mechanical vibration: SAM, US, AU/SWE, vibration
11. Ultrasonics
12. Acoustic emission, including CARP codes
13. Computed tomography
14. Embedded sensors
15. Data fusion
16. NDT of coatings
17. Matching techniques and issues.

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the many techniques available for non-destructive testing of composites.
2. Provide Learners with an overview of the specific techniques appropriate to the defect or damage and the substrate material.
3. Give Learners the tools to choose an effective technique for the issue to be investigated.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the range of non-destructive test techniques
2. Establish an appropriate testing procedure for differing defects or damage conditions.
3. Understand the issues constraining the resolution of each technique, and the ability to detect defects or damage

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance B
Unit title	Multifunctional Composites
Level (Credit points)	H (2)
Unit director	Vijay Kumar Thakur

Unit description

This unit forms part of the Masters level Composites Curriculum. It provides Learners with no prior experience with multifunctional composites with a general introduction to the core concepts in understanding and applying multifunctional composites in engineering applications.

Core subjects to be covered

1. Introduction of multifunctional composites
2. Why use multifunctional composites
3. Design and manufacture
4. Structural functions
5. Non-structural functions
6. Mechanics of multi-functional composite materials and structures
7. Characterization
8. Multifunctional Polymer Composites
9. Multifunctional Cement Composites
10. Multifunctional Ceramic Composites
11. Multifunctional Metal Composites
12. Multifunctional Bio-Composites
13. Multifunctional Nano-Composites
14. Smart Multifunctional Composite
15. Applications
16. Multifunctional Composites for Energy Storage
17. Multifunctional Composites for Energy Harvesting
18. Multifunctional Composites Aerospace Structures
19. Multifunctional Composites for Automotive
20. Multifunctional Composites for Biomedical

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an overview of multifunctional composite materials
4. Identify the needs of multifunctional composite materials
3. Give learners an understanding of the different types of multifunctional composite materials
4. Provide the learners with an understanding of potential applications of multifunctional composite

Statement of learning outcomes

Learners will be able to:

1. Provide a basic overview of the development of multifunctional composite materials
2. How to engineer multifunctional materials to achieve desired properties
3. Understand approaches for optimizing materials properties and their applications

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Composites Curriculum – Unit information

Taught block title	Performance B
Unit title	In-service Damage and Repair
Level (Credit points)	
Unit director	Dr. Hamed Yazdani Nezhad

Unit description

The unit provides an intense teaching of common academic and industrial practices for in-service damage and repair along with the existing aviation certification and repair regulations. The unit also complements and continues Unit: Joining & Assembly

Core subjects to be covered

1. Introduction to damage in composites and composite assemblies
2. BVID
3. Damage in bolted and bonded assemblies
4. Effect of glass transition temperature
5. Serviceability of composite structures
6. Limitations of production NDT
7. Limitations of service NDT
8. Composite bonded repair
9. Bonded repair model
10. Repair failure modes
11. Selection guidance for fastening options
12. Load attraction and stresses in repair
13. Stresses in fasteners and bonds
14. Strength variation along degrading interface
15. Real bond defects
16. How to measure degrading joint strength
17. Repair of BVID
18. Bond failure forensics
19. Sandwich panel service defects
20. Core-to-spar bond in aircraft structures
21. Effect of operational thermal stresses
22. Total load at end of repair vs. design limit load
23. Stress under repair
24. Repair failure due to hot bonding and poor heating
25. Certification of composite joints
26. Aerospace composite repair regulations

Statement of unit aims

The aims of this unit are to:

1. Provide categories of damage occurring in service in high performance composite materials and structures
2. Provide industrial repair procedures for in-service damage

Statement of learning outcomes

Learners will be able to:

1. Appreciate a variety of integration, repair and joining procedures in composite structures from fastening, thermoset adhesive bonding to thermoplastic welding
2. Learn about adhesive bond damage tolerance and failure assessment procedures
3. Learn about composite repair certifications

Methods of teaching	8 lectures, 1 lab demonstration, 1 Boeing 737 visit (Cranfield only)
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance B
Unit title	Recycling and reuse
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the economic and environmental issues arising from the selection of composite systems.

Core subjects to be covered

1. Sustainability: economic, environmental, equity, governance
2. Directives, regulations and legislation
3. Hierachy of end-of-life (HEOL) options, establishing ownership of abandoned components, and the circular economy
4. HEOL1: design for end-of-life
5. HEOL2: the manufacture and marketing phase
6. HEOL3: the use phase ~ how are environmental burdens minimised?
7. HEOL4: reuse of (sub-)components
8. HEOL5: reprocessing thermoplastic composites
9. HEOL6: regeneration of raw materials or their precursors from thermosetting systems
10. HEOL7: recovery and/or degradation of reinforcement fibres
11. HEOL8: Incineration, composting, landfill or scuttle
12. Life Cycle Costing
13. Life Cycle Assessment: ISO 14040 series
14. Environmental Impact Classification Factors
15. "Goal and Scope" and allocation in LCA Software: Simapro, EcoInvent, CES EduPack

Statement of unit aims

The aims of this unit are to:

1. Give Learners an understanding of the economic and environmental issues surrounding the use of composites
2. Provide Learners with an overview of the options for limiting the impact of composites on the environment
3. Give Learners the tools to balance economic and environmental considerations in component design

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the economic issues and environmental burdens of composite systems
2. Establish an appropriate composite system for a specific application
3. Understanding of issues constraining the market for composites

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance B
Unit title	Sustainable composites
Level (Credit points)	H (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It builds on the unit "Introduction to Composites" and "Composites Constituents" to provide Learners with a good understanding of the capabilities and limitations of "sustainable" composites.

Core subjects to be covered

1. Sustainability:
   economic, environmental, equity, governance
2. Circular economy, Bio-economy
3. Natural fibres (animal, mineral, vegetable)
4. Plant fibres: agriculture and extraction
5. Plant fibres: properties and durability
6. The fibre-matrix interface
7. Plant fibres: composites processing
8. Plant fibre composites: properties and durability
9. Plant fibre composites: end-of life
10. Bio-based polymers
11. Bio-degradable polymers Wood-based composites and panel products
12. Life Cycle Costing
13. Life Cycle Assessment: ISO 14040 series
14. Environmental Impact Classification Factors
15. "Goal and Scope" and allocation in LCA
16. Software: Simapro, EcoInvent, CES EduPack

Statement of unit aims

The aims of this unit are to:

1. Give learners an understanding of the range of materials and process options
2. Provide Learners with an overview of the capabilities and limitations of "sustainable" composites
3. Give learners the tools to establish if "sustainable" composites are the most appropriate choice for a specific application
4. Provide the learners with an understanding of process issues constraining the manufacture of natural fibre composites

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the capabilities and limitations of "sustainable" composites
2. Establish if "sustainable" composites are the most appropriate choice for a specific application
3. Understanding of process issues constraining the manufacture of natural fibre composites

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

COMPOSITES CURRICULUM - Unit Information

This unit forms part of the Masters level Composites Curriculum developed by Bristol and Plymouth Universities.

Taught block title	Performance B
Unit title	The broad perspective on composites
Level (Credit points)	M (2)
Unit director	Professor John Summerscales

Unit description

This unit forms part of the Masters level Composites Curriculum. It introduces Learners to the wider context of composites by considering natural materials, composites with a broader range of matrix systems, and what composites might become. Some content will inevitably overlap with other modules!

Core subjects to be covered

1. Particle, whisker or fibre reinforcement
2. Cellulose, chitin and protein
3. Ancient animal artefacts (e.g. bone, antler, ivory, horn)
4. Wooden weapons and workmanship (archery, shields and plant-based products)
5. Structure in nature as a strategy for design (biomimetics)
6. Elastomeric matrices (tyres, hoses, conveyor belts)
7. Self-reinforcing polymers
8. Hierarchical composites
9. Thin-ply flexible structures (including tensile structures)
10. Metal matrix composites (beware galvanic corrosion)
11. Ceramic matrix composites (ceramic, glass, cements, concrete & cob
12. Carbon/carbon composites
13. Functionally graded materials (FGM)
14. Smart materials (one response for each specific stimulus)
15. Intelligent structures (embedded sensor, control and actuator)

Statement of unit aims

The aims of this unit are to:

1. Provide Learners with an extended view of where composites do occur (beyond FRP)
2. Provide Learners with a perspective on how composites may develop in future years.
3. Identify the underlying design principles that have evolved in natural systems
4. Identify appropriate materials for critical performance requirements.

Statement of learning outcomes

Learners will be able to:

1. Provide a clear overview of the extended range of properties achievable dependent on the selected components of the composite system
2. Consider where nature has already evolved a solution to a parallel problem and use that to inspire (not imitate) the design of a new component.
3. Understand some of the limitations of existing systems and think outside the box to develop appropriate designs for challenging environments.

Methods of teaching	7 lectures, 2 lab classes and demonstrations, 1 class exercise
Assessment details if required	Written assignment (85%), 20 minute assessed presentation (15%)
Timetable information	2 days of teaching in a block

Appendix 10- Proposal submitted to HVMC

Tackling Manufacturing Skills Shortages

Quad Chart for Composites Curriculum Proposal

Demand

- Significant **skills shortages** in UK Advanced Manufacturing, critical level in Composites
- Potential for UK Composites market to grow by **£10Bn** in 10yrs
  - **50 000 – 100 000 new jobs**
  - Automation and new tech
- Must move from hand skills to tech skills
- Need **2000 composites trained grads/year**
  - 400 Masters, 100 Doctors
- Only UK Industrial Doctorate Centre in Composites Manufacturing to **close**
  - Final intake 2020 (**next year**)
  - Delivers only 10% of requirement

Proposal

- **Fund a Catapult Fellowship in Composite Skills Development**
  - Sustain activity post-HEFCE
  - Develop sustainable training model
- **Develop and trial full curriculum**
  - Masters level
  - Creative Commons for max usage
  - Multi-university collaboration
  - Deliver in academia or industry
  - Industry already involved
- 10 person-years FTE effort over 2 years
  - Shared across UK academia
  - **Led by Catapult Fellow**

Deliverables

- Funding proposal for delivering and trialling full Composites Curriculum
- Feedback on HEFCE project trials
- Development of full curriculum
- Material made available under suitable IP regime
- Trials of options for course delivery

Stakeholders

- UK Composites Manufacturers
- UK Composites Material Suppliers
- ~15 Academic institutions
- HVMC Centres
  - NCC
  - AMRC
- NPL

Why Composites?

This is demographically a critical time in Composites. The first flowering of advanced composites was the late 1950s to the early 1970s, driven by people who are now retired. The second wave, who entered the industry in the mid-1970s, are on the brink of retirement, including the two leads on the HEFCE project.

We are in danger of losing critical experience if we do not move to capture it now.

The curriculum content has been specified and trial units delivered. The HEFCE project shows good engagement from academia in Composites and a willingness to deliver a collaborative course, utilising the differing expertise of each institution. We can rapidly develop the skills model alongside teaching and learning materials, which can be applied to other critical skills shortages in advanced manufacturing.

The immediate need is to identify and fund an academic champion to sustain the activity beyond the current project. The champion will co-develop with industry and the Catapult a vision and funding proposal for a sustainable model of developing advanced training capacity in the UK, allowing the industrial strategy to come to fruition without skills shortages limiting national opportunities.

The HVMC has played a crucial role in the development of the UK Composites Strategy and the very significant government investments that have been made and is ideally placed to provide leadership and direction to the skills developments needed in parallel to the technology and strategy developments. *Lack of suitably trained staff will render the UK's National Composite Strategy undeliverable.* This proposal is intended to deliver a method to remedy that problem.

Appendix 11- Staff figures from BMW's i3 programme

BMW have provided the following information on staffing levels needed for the i3 production:

Initial stage; 10 – 6 years before start of production

- Research and Development "Skunk Works"
  - Incubators – Present in Body-in-white, Crash and Durability 5 – 10 people, composite trained and highly experienced Engineers and PhDs
  - Sizing and Construction – Engineering level, 5 – 10 people
- Manufacturing
  - Incubators – 5 people with background in composite manufacturing, highly experienced Engineers and PhDs
  - Production development – 5 -10 engineers or highly experienced technicians

Development stage; 6 -2 years before start of production

- Research and Development
  - Additional engineering staffing up to 20 people
- Manufacturing
  - Prototype manufacturing at max. capacity
  - 10 additional engineers
  - Up to 40 technicians
- Outreach
  - Staffing should be available to perform internal training and built knowledge base

Industrialization stage, 2 – 0 years

- Research and Development
  - Scaling internally, not necessarily additional recruitment
- Manufacturing
  - Scaling to automotive volume
  - Focus on quality control and NDE, process optimization, additional 10 engineers
  - Additional technicians for at volume manufacturing, 20 technicians
- Plant and assembly
  - Quality control and process management, 10 engineers
  - Technicians not necessarily composite trained

Rumours state that 2billion$US[24] were spent on development of the i3 and it is calculated to be profitable at 20,000 units per year[25]. Sales in 2015 were 22,000 per year[26] and reached 34,000 per year in 2018[27]. Prices in the UK start at £30680[28] per car. This gives a 2018 BMW i3 global market size of ~£1x10^9.

[24] http://www.forbes.com/sites/neilwinton/2014/05/15/bmws-electric-brand-will-lower-co2-cost-a-lot-and-pay-off-big-long-term/#256bf620167b [online, 30/08/19]
[25]] http://www.forbes.com/sites/joannmuller/2015/01/04/video-unlocking-the-secrets-of-bmws-remarkable-car-of-the-future/#7c07c445366c [online, 30/08/19]
[26] BMW Group.Annual Report. 2015.
[27] https://www.press.bmwgroup.com/global/article/detail/T0289883EN/bmw-group-remains-world%E2%80%99s-leading-premium-automotive-company-in-2018?language=en[online, 30/08/19]
[28] https://insideevs.com/news/318505/bmw-sets-lease-price-on-i3-at-565-in-the-uk-369-priced-from-25680/[online, 30/08/19]

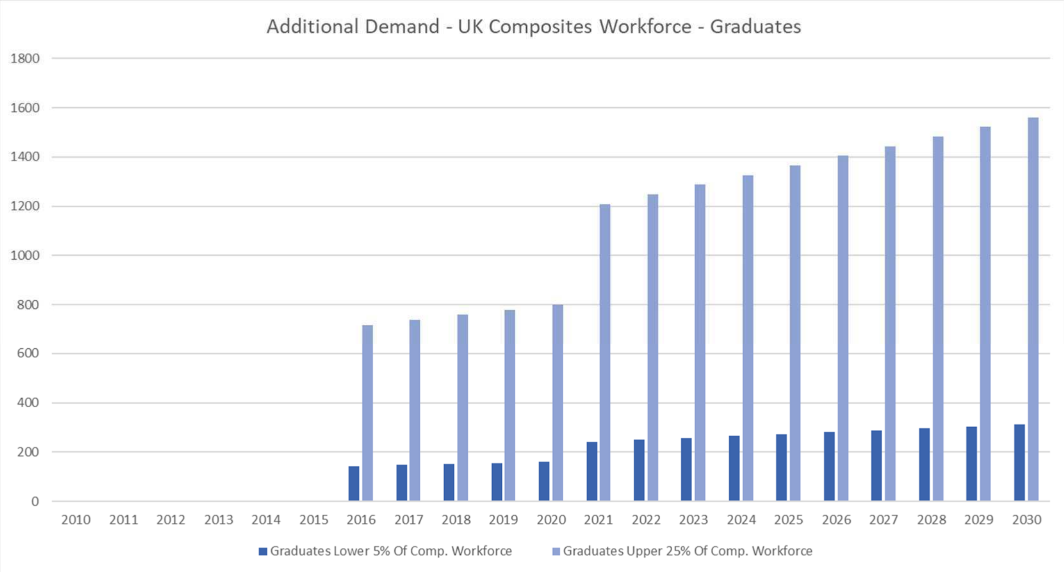
Appendix 12- Estimate of demand signal

NOTES

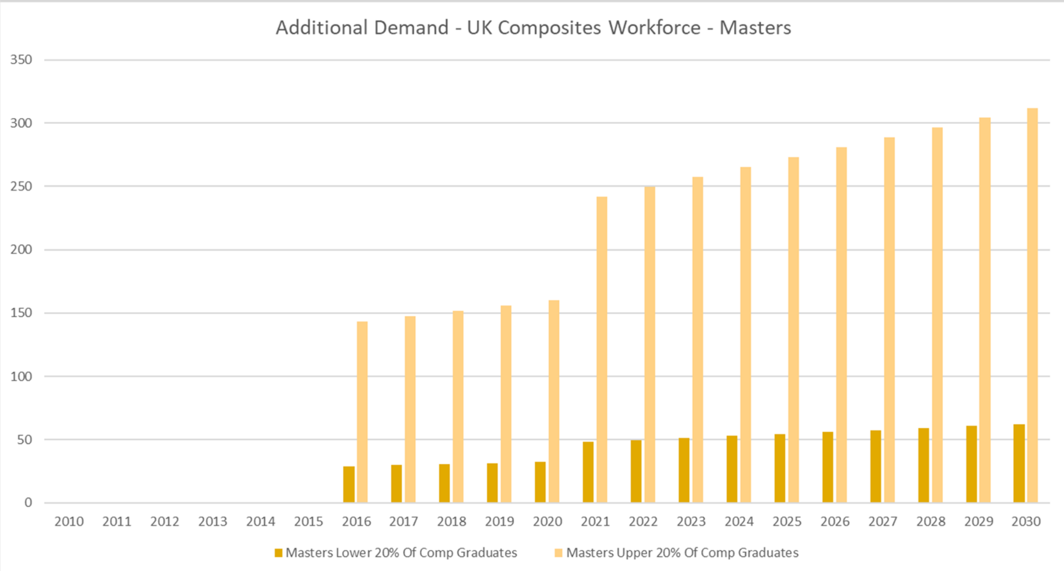
Purpose	Cross check KP figures with overall UK student numbers Seek alignment with previous manpower estimations (PS 2010)

Comments

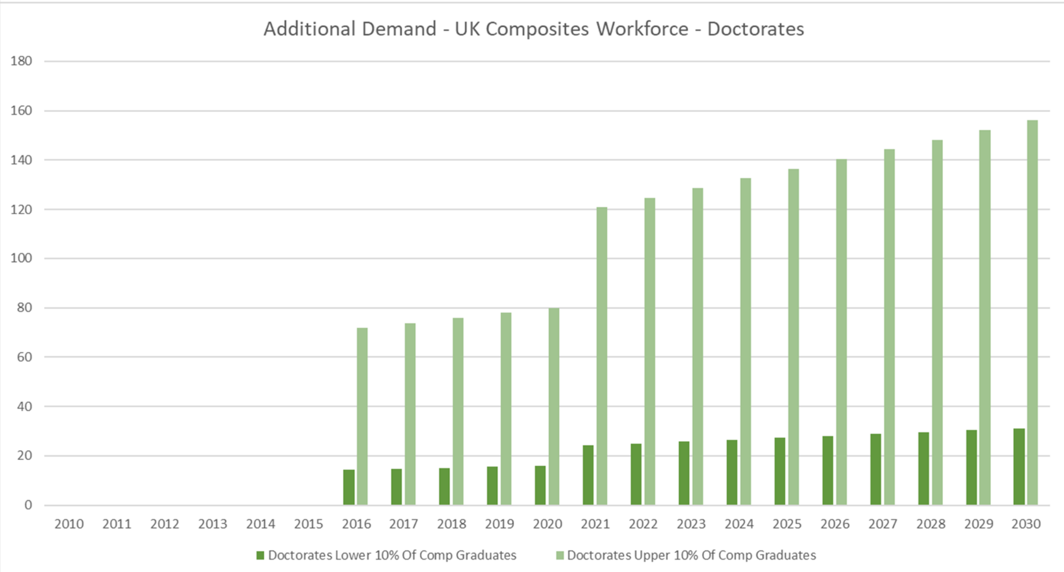
W/S KP-Based	Take capital intensive FTE figure - least worst case But need to highlight increased technology / automation platforms Alternatively use extremes to represent all / part composites needs Beige box containes EngineeringUK figures, assume representative from 2015 (latest) *(Depressing as UK headline numbers)* This shows that KP workings come up with a reasonable level of need ***Baseline seems to be to*** ***1. Grow composites content within Graduate level (during course or CPD)*** ***2. Significant increase of Masters input, although we need to assess current UK numbers*** ***3. At least double Doctorates BUT this does not track R&D that leads to automation*** *PS View* *Clear need to increase 'total composites' people at '5%-end'* *Equally clear that significantly greater demand for spreading composites across profession* *We will need to comment on the non-graduate portion of the workforce* *Ambitious with the anticipated high levels of automation...... (circular argument)*
W/S Strategies	Figures from E&Y 2010 and CLF 2014 reports Unfortunately not consistent measures / definitions (Revenue, GVA, etc. or what is a composite) Major discrepancy is a delay to aero growth beyond 2015 E&Y figures Overall, we can make case to use upper CLF figures Then consistent with annual FTE growing value approach CAGR for workforce comes out around 6% which builds in the higher output values (productivity)
PS 2010	Included to illustrate how we might approach a more detailed breakdown By 'region' and sector



Additional Demand - UK Composites Workforce - Graduates
1800
1600
1400
1200
1000
800
600
400
200
0
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030
Graduates Lower 5% Of Comp. Workforce
Graduates Upper 25% Of Comp. Workforce



Additional Demand - UK Composites Workforce - Masters
350
300
250
200
150
100
50
0
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030
Masters Lower 20% Of Comp Graduates
Masters Upper 20% Of Comp Graduates

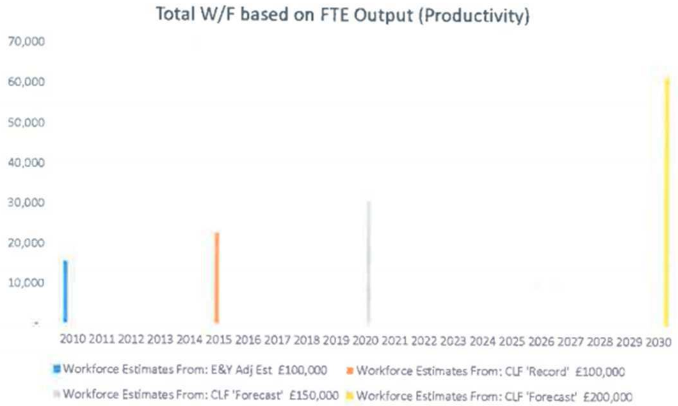


Additional Demand - UK Composites Workforce - Doctorates
180
160
140
120
100
80
60
40
20
0
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030
Doctorates Lower 10% Of Comp Graduates
Doctorates Upper 10% Of Comp Graduates

TRENDS

ADDITIONS TO UK COMPOSITES WORKFORCE

	Workforce Estimates From: E&Y Adj Est £ 100,000	CLF 'Record' £ 100,000	CLF 'Forecast' £ 150,000	CLF 'Forecast' £ 200,000	Straight-Line Fit	Annual Growth	Annual Loss of 5%	Total Annual Demand	Graduates Lower 5% Of Comp. Workforce	Graduates Upper 25% Of Comp. Workforce	Masters Lower 20% Of Comp Graduates	Masters Upper 20% Of Comp Graduates	Doctorates Lower 10% Of Comp Graduates	Doctorates Upper 10% Of Comp Graduates	*Other Lower Of Comp. Workforce*	*Other Upper Of Comp. Workforce*
2010	15,510				15,510		776	**776**								
2011					16,986	1,476	849	**2,325**								
2012					18,462	1,476	923	**2,399**								
2013					19,938	1,476	997	**2,473**								
2014					21,414	1,476	1,071	**2,547**								
2015		22,890			22,890	1,476	1,145	**2,621**								
2016					24,535	1,645	1,227	**2,871**	144	718	29	144	14	72	*2,685*	*1,938*
2017					26,179	1,645	1,309	**2,954**	148	738	30	148	15	74	*2,762*	*1,994*
2018					27,824	1,645	1,391	**3,036**	152	759	30	152	15	76	*2,839*	*2,049*
2019					29,469	1,645	1,473	**3,118**	156	780	31	156	16	78	*2,915*	*2,105*
2020			31,113		31,113	1,645	1,556	**3,200**	160	800	32	160	16	80	*2,992*	*2,160*
2021					34,238	3,124	1,712	**4,836**	242	1,209	48	242	24	121	*4,522*	*3,264*
2022					37,362	3,124	1,868	**4,992**	250	1,248	50	250	25	125	*4,668*	*3,370*
2023					40,486	3,124	2,024	**5,148**	257	1,287	51	257	26	129	*4,814*	*3,475*
2024					43,610	3,124	2,181	**5,305**	265	1,326	53	265	27	133	*4,960*	*3,581*
2025					46,734	3,124	2,337	**5,461**	273	1,365	55	273	27	137	*5,106*	*3,686*
2026					49,858	3,124	2,493	**5,617**	281	1,404	56	281	28	140	*5,252*	*3,792*
2027					52,983	3,124	2,649	**5,773**	289	1,443	58	289	29	144	*5,398*	*3,897*
2028					56,107	3,124	2,805	**5,930**	296	1,482	59	296	30	148	*5,544*	*4,002*
2029					59,231	3,124	2,962	**6,086**	304	1,521	61	304	30	152	*5,690*	*4,108*
2030				62,355	62,355	3,124	3,118	**6,242**	312	1,560	62	312	31	156	*5,836*	*4,213*



	830	EU	4%	Other	60%
	1,380	Other	6%		

	UK
Graduation at Degree	17,400
Non UK *31%*	
Graduation at Masters	3,965
Non UK *75%*	
Graduation at Doctorate	1,188
Non UK *60%*	

Of these, exclude Civil, Chemical, Electrical and Electronic			
General, Mechanical, Aero	16,180	UK	75%
Production and Manufact'g	1,465	EU	7%
	3,870	Other	18%
Graduate leakage from Engineering			
Remain in immediate workforce	68%	UK	
Of these, remaining in engineering	**70%**	**UK**	**Number quoted on table 8.7** **8,210**

Therefore need to impact			
%tage of graduates	3%	Assume intensive composites	NEEDS DEFINITION
%tage of graduates	15%	Assume some composites	THIS FEELS OK - OR UNDERSTATED

		lower	Composites of UK total	upper	Composites of UK total
POST GRADUATES PER YEAR					
Of graduate numbers, Masters	20%	50	1%	250	6%
Of graduate numbers, Doctorates	10%	25	2%	125	11%

		of lower	of upper	
Current UK Masters output	10	20%	4%	NEED DATA
KP statement of				
Current Doctorate output	15	60%	12%	

FROM STRATEGIES

E&Y 2010 Report	2010	FORECAST 2015	FORECAST 2020	FORECAST 2030
Production Demand(£m)	£ 1,255	£ 1,993	£ 2,252	
Aero	£ 675	£ 1,048	£ 1,009	
	54%	53%	45%	
Auto	£ 143	£ 389	£ 565	
	11%	20%	25%	
Other	£ 437	£ 557	£ 678	
	35%	28%	30%	

CLF 2014		'RECORD' 2015	FORECAST Upper 2020	FORECAST Upper 2030	
Aero		£ 273	£ 1,155	£ 3,590	
Defence		£ 383	£ 952	£ 1,146	
Auto		£ 380	£ 530	£ 3,490	
Rail		£ 55	£ 98	£ 155	
Construction		£ 362	£ 640	£ 1,520	
Marine		£ 220	£ 270	£ 370	
O&G		£ 15	£ 337	£ 1,100	
Renewables		£ 601	£ 685	£ 1,100	
	£ 1,551	£ 2,289	£ 4,667	£ 12,471	2010 based on E&Y + 2015 discrepancy

Discrepancy (CLF - E&Y)	2015	2020	
Total	£ 296	£ 2,415	Other sectors growth, ? renewables
	13%	*52%*	
Aero	£ (775)	£ 146	
Aero (inc Defence)	*£ (392)*	*£ 1,098*	

Auto		£ (9)	£ (35)		
Workforce Calculation	2010	2015	2020	2030	
Use FTE Output Value	£ 100,000	£ 100,000	£ 150,000	£ 200,000	Initially stable productivity Reflects growing automation
Calculated Total	15,510	22,890	31,113	62,355	
					FEELS OK
Previous upside forecast	10,950	22,791			
WF growth from 2015			8,223	39,465	
		Growth	36%	172%	
		CAGR	6%	5%	

Appendix 13- Example Assessments from Existing Courses

Integrated Learning Package, University of Bolton

Guidelines for Integrated Learning Package preparation

Extracts taken from the Programme Handbook

"Written work is in the form of an assignment or an **integrated package and consists of three parts**, each with set times and deadlines for submission. All coursework is assessed in parts and feedback will be given during the allocated period of self study. Such work may take the form of essays, assignments, projects, seminars, case study analyses etc.

The first part of the assessment will consist of questions requiring short answers, and simple problem solving exercises. This will develop the participant's knowledge and comprehension with a certain degree of application to new problems. It is expected that all participants, who have satisfactorily completed the learning package will be able to complete this part without difficulty. This will boost the confidence of participants and encourage them to complete the more challenging work to follow.

The second part will consist of two parts. The first is a series of in-depth problems with structured questions leading participants to their solution, and in so doing, develop problem solving skills. The second is a comprehension exercise from a published scientific work. This will require participants to apply the knowledge and understanding they have acquired, and expose them to techniques of investigation and problem solving.

These will prepare participants for the **final part of the assessment, which will involve synthesis and evaluation of the material they have now become familiar with, and using it to propose a solution to a novel problem, though the medium of a case study.** This will require independent trawling for appropriate data sources and supporting information and a full account of the reasons for their choice of solution. The nature of the problems posed will be open-ended, and without a unique (i.e. right or wrong) solution. Key skills will be developed, and assessed at appropriate stages during each part of the assignment".

[29] Material included with the kind permission of Professor Baljinder Kandola

Students have upto a maximum of 3 months by which to complete these works, tutorial and help is offered via e-mail, post and telephone calls.

M.Sc. Advanced Materials

Materials and Fire Retardants

Integrated Learning package: Fire Retardants

Part 1 (20 marks)

Explain the term intumescence with regards to flame retardancy. Give examples of commercially available intumescent flame retardants and state applications where intumescent flame retardants perform effectively as compared to other flame retardant systems.

Part 2 (30 marks)

Existing UK fire (safety) regulation for nightwear requires the fabric to be tested in accordance with BS 5438. However, a high street departmental store requires that the fabrics used to manufacture nightwear gives minimal burn injuries in the event of fire. Discuss the flammability criteria to be considered and propose a possible test method to assess severity of burn injuries.

OR

Industrial fabrics are usually high count, tightly woven materials that find applications in highly engineered structures where high strength, dimensional stability, fire resistance and low cost are essential requirements. Discuss the possibility of using thermoplastic nanocomposite fibres for producing such industrial fabric.

Part 3 (50 marks)

A supplier is required to provide ship building company with fire doors for a passenger cruise liner. Considering the fire hazard on-board, discuss and critically analyse the types of material and environmentally friendly flame retardant treatments that could be used for fire doors. Furthermore, smoke and toxicity is a major fire hazard in mass transport vehicles. While selecting the materials as well as FR treatment, discuss smoke and toxicity regulations and suggest possible methods of reducing smoke and toxicity hazard.

Your input on this ILP should not be less than 4000 words

M.Sc. Advanced Materials

Materials and Fire Retardants

Integrated Learning package: Fire Retardant Composites

Part 1 (20 marks)

A fibre reinforced composite contains two or more components and for certain applications spacers are used between laminates to increase volume.

Discuss how different components influence the flammability of a composite structure.

Part 2 (30 marks)

Discuss three different resins commonly used in composites, their positive and negative characteristics, flammability and toxicity. You can include thermoplastic and thermoset resins in your discussion.

Discuss different methods of reducing the flammability of composites prepared from each resin type using 8 layers of glass or carbon fabric reinforcement.

Part 3 (50 marks)

The use of composites in aerospace, marine and automotive systems as a means of decreasing weight and enhancing survivability, without reducing personnel safety, has been considered for sometime. For each application, there are different fire, smoke and toxicity, and other relevant regulations. For load bearing structures, retention of mechanical properties after heat/fire exposure also needs to be considered.

Undertake a study with ONE of the commercial applications and considering the fire hazards, discuss the type of materials and fire retardant treatments that could be used. You need to discuss this in view of different regulations for that particular application.

Your input on this ILP should not be less than 4000 words

References :

1. A.R.Horrocks and D.Price (eds), *Fire Retardant Materials,* Cambridge, Woodhead Publishing Ltd, 2001.
2. A P Mouritz and A G Gibson, Fire Properties of polymer Composite Materials, Springer Netherlands, 2006.
3. G.L.Nelson and C.A.Wilkie *(eds) Fire and Polymers*, American Chemical Society Symposium Series 922, 2006.
4. M Le Bras *et al* (eds), ‘Fire Retardancy of Polymers: The use of mineral fillers in micro- and nano-composites’, Royal Chemical Society, Cambridge, 2005.
5. J. Troitzsch (ed), *Plastics Flammability Handbook,* Hanser Publishing, Cincinnati 2004.
6. G.L.Nelson and C.A.Wilkie (eds) *Fire and Polymers*,, American Chemical Society Symposium Series 797, 2001
7. G.Camino, M.Le Bras, S.Bourbigot and R.Delobel (eds), '*Fire Retardancy of Polymers : The Use of Intumescence',* The Royal Society of Chemistry, Cambridge, 1998.
8. A.C.Long (ed), ‘*Design and Manufacture of textile composites’* Woodhead Publishing Ltd, Cambridge, 2005.

M.Sc. Advanced Materials

Materials and Fire Retardants

Integrated Learning package: Fire Retardants

Part 1 (20 marks)

Explain the term flame retardancy. Discuss different type of flame retardants based on:

- Chemical composition and effectiveness
- Method of application to different polymer polymers
- Environmental issues during processing and service life
- Durability to environmental factors

Part 2 (30 marks)

You have been tasked to flame retard a thermoplastic and a thermoset polymer. Critically review various options of flame retarding these two polymer types taking one example of your choice for each polymer and its potential end use application.

Part 3 (50 marks)

An aerospace company approached a supplier to provide seats for a new aircraft. Considering the fire safety regulations for aerospace, discuss and critically analyse the types of material and environmentally friendly flame retardant treatments that could be used for these seats. Furthermore, smoke and toxicity is a major fire hazard. While selecting the materials as well as FR treatment, discuss smoke and toxicity regulations and suggest possible methods of reducing smoke and toxicity hazard.

Your input on this ILP should not be less than 4000 words

M.Sc. Advanced Materials

Materials and Fire Retardants

Integrated Learning package: Fire Retardant Composites

Part 1 (20 marks)

A new flame retardant chemical has been synthesized in our laboratory and you are tasked to study its effectiveness as a flame retardant in a polymer. The chemical can be melt blended with the polymer. Discuss various methods that can quantitatively and qualitatively demonstrate its flame retardant properties.

Part 2 (30 marks)

You are provided with a copy of the paper entitled 'DNA: a novel, green, natural flame retardant and suppressant for cotton', by Alongi et al, Journal of Materials Chemistry A (2013). Briefly summarise this paper and apply the knowledge you have acquired from the lecture notes and literature to discuss strengths and weaknesses of this paper.

Part 3 (50 marks)

You will be provided with:

- A polymer
- A + Phosphorus based flame retardant
- A + Nanoclay

Perform appropriate small scale and lab scale flammability tests in the laboratory. Analyse the results and relate to the mechanism of action of different types of flame retardants. Based on results suggest strengths and weaknesses of each test. Provide overall flammability index of these samples.

Your input on this ILP should not be less than 4000 words

References :

1. A.R.Horrocks and D.Price (eds), *Fire Retardant Materials,* Cambridge, Woodhead Publishing Ltd, 2001.
2. A P Mouritz and A G Gibson, Fire Properties of polymer Composite Materials, Springer Netherlands, 2006.
3. G.L.Nelson and C.A.Wilkie *(eds) Fire and Polymers*, American Chemical Society Symposium Series 922, 2006.
4. M Le Bras *et al* (eds), ‘Fire Retardancy of Polymers: The use of mineral fillers in micro- and nano-composites’, Royal Chemical Society, Cambridge, 2005.
5. J. Troitzsch (ed), *Plastics Flammability Handbook,* Hanser Publishing, Cincinnati 2004.
6. G.L.Nelson and C.A.Wilkie (eds) *Fire and Polymers*,, American Chemical Society Symposium Series 797, 2001
7. G.Camino, M.Le Bras, S.Bourbigot and R.Delobel (eds), '*Fire Retardancy of Polymers : The Use of Intumescence',* The Royal Society of Chemistry, Cambridge, 1998.
8. A.C.Long (ed), ‘*Design and Manufacture of textile composites’* Woodhead Publishing Ltd, Cambridge, 2005.

Question 1

Read the paper "Effects of Defects on the Interlaminar Performance of Composites"(*), authored by Makeev, Nikishkov, Seon and Armanios. Within a maximum of 2000 words:

1) Illustrate the technique employed by the authors to detect the presence of porosity in ASTM 6415 curved-beam coupons and describe the main features of the voids in terms of shape and locations;

[5%]

2) Discuss the influence of the void location and size on the measured static interlaminar tensile strength. In particular, consider the following two aspects of the work by Makeev et al.: 2.a) Is it possible to back-calculate the interlaminar strength of the void-free material from the experimental data? 2.b) What do the stress criteria originally proposed by Whitney and Nuismer and employed in the paper postulate?

[15%]

3) Discuss the influence of porosity on the fatigue performance of curved-beam coupons.

[10%]

You may reference additional sources from the literature where appropriate to either support or rebut the results obtained in the paper and the conclusions drawn therein.

[30] Material included with the kind permission of Dr Giuliano Allegri

Question 2

The interlaminar tensile strength of a prepreg-based glass-epoxy composite system has to be characterised adopting the ASTM D6415 standard. L-bend coupons have been tested by means of the four- point bending rig shown in Fig. Q2.1. The material can be considered quasi-isotropic; it has a longitudinal Young's modulus of 161 GPa and a transversal Young's modulus of 11.4 GPa. The cured ply thickness is 0.127 mm and the coupons have been manufactured laying-up 32 plies with 0° orientation.

In the testing rig, the roller diameter is D = 10 mm, while the roller distance is d_x = 12.5 mm. All the other rig and coupon dimensions not explicitly stated here comply with those prescribed in the standard.

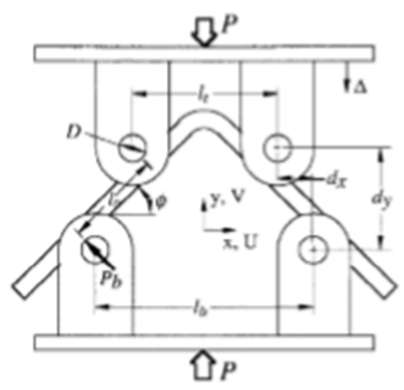


Figure Q2.1: Sketch of loading rig for ASTM D6415

During the tests, the rig displacement Δ has been measured by means of a video displacement gauge; the applied force has been recorded by means of a calibrated 10 kN load cell. A total of 5 coupons were tested, all showing sudden failure with no sub-sequent reloading. The cross-head displacement and load values at failure are listed in Tab. A2.1.

Δ (mm)	**P (kN)**
5.1	2.90
5.2	2.84
4.9	2.93
4.8	2.45
5.0	2.92

Table A2.1: Displacement and load at failure

1) Compute the interlaminar tensile strength values corresponding to each of the test results presented in Tab. A2.1, using the exact solution from Lekhnitskii;

[20%]

2) Calculate the B-basis allowable for the interlaminar tensile strength from the data in Tab. A2.1, rejecting eventual outliers by means of the maximum normed residual criterion

[10%]

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Question 3

The mode II fracture toughness of a fibre-reinforced carbon/epoxy composite has to be characterised according to the ISO 15114:2014 standard, i.e. using "end loaded split" (ELS) coupons. The material cured ply thickness is 0.1375 mm. Unidirectional 0° specimens are manufactured by laying up a square plate comprising 24 plies, with a Teflon release film of negligible thickness inserted between the 12^{th} and 13^{th} ply. After autoclaving, the plate is cut into coupons 190 mm long and 20 mm wide.

1) A compliance calibration is carried out on one of the coupons using the "inverse ELS" configuration illustrated in the standard. The results of the calibration tests are the following:

L clamp (mm)	C (mm/N)
50	5.832E-03
60	9.261E-03
70	1.563E-02
80	2.439E-02
90	3.594E-02
100	3.930E-02
110	5.065E-02

Table A3.1: Data from compliance calibration

where "L camp" represents the distance between the loading axis and the clamp. From the data presented in the table above, estimate:

a) The flexural modulus of the coupon;

[5%]

b) Estimate the clamp correction to the specimen length Δ_{clamp};

[5%]

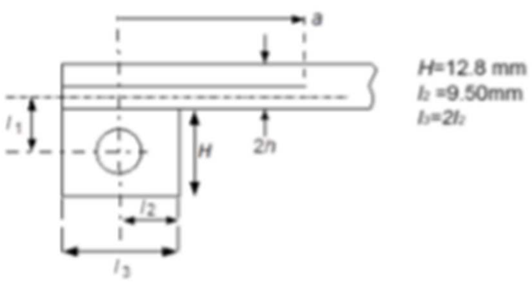


Figure Q3.1: Arrangement of loading block in ELS coupons

2) One of the coupons described above is tested in the "direct ELS" configuration. A tip shear force is applied via a loading block, having the dimensions shown in Fig. Q3.1 The coupon is clamped at a distance of 110 mm from the loading axis. The length of the insert film is 60 mm from the loading axis; before the actual test, the coupon is pre-cracked in mode II, thus giving an initial crack length of 62 mm.

The following tip displacement and shear force values are recorded during the test as the delamination propagates in the gauge section:

Displacement (mm)	Load (N)
14.7	115.7
14.9	114.6
15.0	106.1
15.1	104.0
15.3	88.9
15.4	96.1
15.9	86.2
16.7	77.3
16.8	87.5
16.9	83.8
17.0	78.4
17.9	79.6
18.1	79.4
18.4	77.9
18.5	77.7
18.6	76.5

Table A3.2: Data from ELS test

a) Plot the mode II R-curve corresponding to the data in Tab. A3.2 using the CBTE method and including the effects due to large rotations and the presence of the loading blocks;

[20%]

b) Discuss how mode I pre-cracking would have affected the R-curve trend.

[10%]

****

IDC in Composites Manufacture

Unit 7 - Design for Manufacture of Composite Structures (AENGM0024)

Unit Director: Dr Carwyn Ward

Engineers' House (Clifton Down, Bristol): Monday - Friday (Wednesday and Thursday AM only); University of Bristol (Bristol Composites Institute (ACCIS) and the Queens Building Laboratories): Wednesday PM, and; off-site visit: Thursday PM

21-25 January 2019

Preamble

This document sets out the assignment activity for Unit 7.3. The assignment has been separated into two parts, with an 80:20 split delivered as a written assignment and a video log (respectively). The total mark is out of 100. The intention is that course participants will deliver both parts at the same time, and that the submission deadline is ***16:00 on Friday 29th March*** via the submission point on Blackboard. The Unit 7.3 course documents folder on Blackboard will have examples of previous assignments for reference, and in particular showing good examples of the video log. The Unit Director is available to discuss the assignment content in person or by email, for aspects such as development ideas and reviewing an interim report, up to one week before the submission deadline.

Part 1. Written Assignment - 80 marks total

As a typical written report, of style to be determined by the author, please complete all of the following sections (but it must be clearly readable to the examiners). Note that it is advisable that the report is set out as per the sections below, for ease of marking. It is not necessary to employ the outputs of the Unit 2 written submission as your product/structure choice. New choices of component etc. are allowed for this assignment, if not encouraged.

1. *Redesign of a structure currently made in advanced composites*

(50 marks, 10 pages max.)

a. Identify the critical design requirements of the product/structure, and how the current product/structure is manufactured

(10 marks)

b. Identify any aspects of the current design that might be expected to give rise to problems (such as defects and variations) in manufacture or in-service; and how these might be tackled by risk management in the manufacturing processes, without undertaking a full redesign of the product/structure

(15 marks)

c. Carry out a conceptual redesign of the product/structure to improve the manufacturability of it, whilst still meeting your previously identified critical design requirements

(15 marks)

d. Comment, and provide evidence, on the anticipated impact of the improved manufacturability of the product/structure; concentrating on the costs of manufacture, and its robustness to defects or variations

(10 marks)

2. *Design for experimental simulation of a manufacturing process*

(30 marks, 6 pages max.)

Consider the manufacturing process for the part that had been redesigned, and explore how you would design an experiment that would allow for the simulation of all or part of the manufacturing

1

[31] Material included with the kind permission of Dr Carwyn Ward

process in a standard desk-top uniaxial testing machine. To achieve this task the aim is to first understand the manufacturing process sufficiently such that all of the important process variables are understood. It will then be possible to extract the repeatable and controllable key process variables as experimental inputs that will work within the confines of the test machine, in order to deliver measurable experimental outputs that will enable understanding of the process. It may be important to consider visual recording tools such as video cameras for aspects of the experiment, as much as direct measurements through force or displacement. The following are four different examples of published works demonstrating the experimental simulation of manufacturing processes or elements of a manufacturing process, and can be used as examples for how to achieve this task (although only two of the examples employ the use of a uniaxial test machine):

- H Jones, A Roudaut, A Chatzimichali, K Potter, C Ward (2017) The Dibber: Designing a standardised handheld tool for lay-up tasks. Applied Ergonomics 65
- M Elkington, D Bloom, C Ward, A Chatzimichali, K Potter (2015) Hand layup: understanding the manual process. Advanced Manufacturing: Polymer & Composites Science 1 (3)
- G Tan, JW Hartley, E Withers, J Kratz, C Ward (2015) Towards the development of an instrumented test bed for tufting visualization. In: SAMPE Europe Conference 2015 AMIENS
- DH-JA Lukaszewicz (2011) Optimisation of high-speed automated layup of thermoset carbon-fibre preimpregnates. Thesis (PhD) University of Bristol

Part 2. Video Log Assignment - 20 marks total

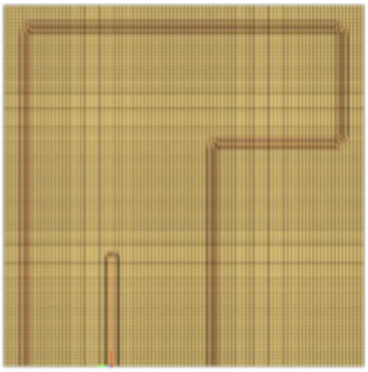
Produce a short (5 minutes max. playing time) animation or video (self-playing presentations will be considered) that presents the product/structure used in Part 1, its redesign process, and any special point of interest the author/director may want the viewer to consider. The submission should aim to take the form of a reflective log of the submission activity, and should be suitable for a generalist audience at "A-level" schooling standard.

(20 marks, video/animation)

C Ward
January 2019

IDC, Unit 5, Processing Simulation and Control in Composite Manufacture, AENGM0019, September 2018.

Simulation of Resin Flow and Cure in Liquid Composite Moulding Processes



A floor panel is to be produced using liquid moulding technology (rigid double-sided RTM mould). The component is made from a balanced carbon 2×2 twill fabric and high temperature epoxy resin. The in-plane dimensions of the panel are ~1.0×1.0 m. The component is made of 28 plies. To meet nominal structural requirements (where manufacturing was not considered), the plies needs to have orientation of 0/90° with respect to the panel edges.

For RTM process, a pressure pot or a pump (max. flow rate 8.33×10^{-5} m^3/s) is to be used. The maximum admissible injection pressure, which must not be exceeded for safety reasons, is 0.4 MPa (absolute value). Thickness of cavity in RTM must be chosen to reach nominal fibre volume fraction of 60%. For conservative design a vacuum pump is considered to be not available – hence, pressure at vents is 0.1 MPa and entrapment of air behind the flow front bears a risk of an impregnation defect. In addition, the effective surface heat transfer coefficient of the non-heated side of the curing assembly is 2.5 $W/m^2/°C$, and the initial degree of cure of the resin is 3.5%.

Assume that the heat transfer can be approximated by an 1-D through thickness solution of the heat conduction problem, with one sided following the temperature of a heated tool and the other approximated by a natural convection boundary condition (the effective surface heat transfer coefficient is given below) and an ambient temperature of 55°C. The component can be considered fully cured when the minimum degree in it is 92.5%. The mesh and geometry are defined in an input file "CourseWork_2018.pc" (mesh) and "CourseWork_2018.igs" (geometry).

For the RTM simulations activate the air entrapment option. Injection gate or vents can be placed either on the boundary of the geometry or inside the cavity. For circular injection gates use a radius of 0.01 m.

Discussion: questions to address in presentation/report

Infusion. Design the position of vents, injection gates, and/or runners to optimise the injection configuration with respect to complete filling of the cavity, minimisation of the fill time, and preventing impregnation defects.

Consider internal race tracking along the concave corners of the panel. Calculate and assign the permeability of the race-tracking channels assuming no fillets in the mould corners.

Using cure kinetics model and rheological properties of the resin, choose infusion temperature to make sure that the mould is filled before resin gels (assume that 20% degree of cure cannot be exceeded during the infusion).

Draping. Consider the lay-up and draping of preform prior to infusing it [1]. Optimise draping procedure to minimise possibility of wrinkling on the one hand, maximising performance (by aligning the fibre angles to the nominal configurations suggested by the design where possible) and avoiding excessive deviation from the nominal fibre volume fraction (trying to avoid below 50% or higher than 70%).

1

[32] Material included with the kind permission of Dr Dmitry Ivanov

IDC, Unit 5, Processing Simulation and Control in Composite Manufacture, AENGM0019, September 2018.

Draping and infusion. Consider the evolution of permeability caused by shearing of preforms. Consider distribution of fibre volume fraction over the part. Manually define zones where the fibre orientation can be considered constant. Calculate and assign representative values of fibre orientation and permeability to the segments of the panel (assuming that the properties are constant over the zone area). Consider local permeabilities in injection simulation - how does the draping change the infusion characteristics, such as flow front shapes and fill times, of this component (see [2] as an example)?

Consolidation. Consider fibre paths where defects are most likely to occur. Calculate the excessive length of fibres associated with the differential compaction in consolidation process. Indicate areas with high risk of wrinkling and other fibre path defects. Suggest a defect mitigation strategy. Estimate force required to close the mould.

Cure. Find the recommended cure profile for the resin (Hexcel RTM6) (recommended by supplier of the resin or suggested in literature) and simulate the cure of the component. Report and comment on the temperature and degree of cure evolution. Identify the cure time, compare this with the cure profile recommendation, and suggest optimum cure cycle. Can you suggest a better cure cycle for this component? - shorter curing time but without exceeding 5°C of data sheet curing temperature anywhere through the thickness of the laminate.

Cure and variability. For a representative thickness, simulate the influence of variability by executing extreme case scenarios for the stochastic variables of the process. Approximate the probability distribution of cure time resulting from process variability. Discuss the recommended cure cycle in light of stochastic simulation. Comment on the role of stochastic and deterministic simulations. Discuss the contribution of cure to flow during injection (coupled flow/cure simulations are not required).

Input data and models

Cure kinetics of the injected resin is well described by the following model:

$$\frac{d\alpha}{dt} = \frac{Ae^{\left(\frac{-E}{RT}\right)}}{1+e^{C(\alpha-\alpha_o-\alpha_T T)}}(1-\alpha)^n \alpha^m \qquad (1)$$

The thermal properties of the curing composite and the cure kinetics parameters of the kinetics equation are given in Table 1, whilst the effective surface heat transfer coefficient the non-heated side of the curing assembly is 2.5 W/m²/°C, and the initial degree of cure of the resin is 3.5%.

Table 1: Properties of RTM6 for heat transfer and cure kinetics models

Property	Value
The density of the epoxy kg/m³,	1.11×10^3
Thermal conductivity of the composite in the thickness direction, W/m/°C	0.32
Specific heat capacity of the composite, J/g/°C	1.6
Total reaction heat, J/g	460
A, 1/s	22000
E, J/mol	58000
n	1.3

2

m	1.2
C	68
α_o	-2.25
α_T, 1/°K	0.0072

Viscosity evolution of RTM6 can be described by Castro-Macosko model:

$$\eta = \eta_{g0} exp\left(-\frac{C_1(T-T_{g0})}{C_2+T-T_{g0}}\right)\left(\frac{\alpha_g}{\alpha_g-\alpha}\right)^{A+B\alpha} \quad (2)$$

Material parameters for the viscosity model are derived by Lionetto et al [4] and summarised in Table 2.

Table 2: Parameters for resin viscosity model

Property	Value
C_1	31.6
C_2, K	33.5
α_g	0.42
T_{g0}, K	258
η_{g0}, Pa×s	$2.0*10^9$
A	5.58
B	7.20

Process variability is governed by uncertainty in the parameters listed in Table 2, whilst all variables are considered uncorrelated.

Table 3. Uncertainty of the cure process.

Variable	Distribution	Standard deviation
Tool temperature	Normal	2 °C
Surface heat transfer coefficient	Normal	0.4 W/m^2/°C
Activation energy	Normal	1000 J/mol

For each material zone calculate thickness and permeability. The in-plane permeability for non-sheared fabric of fabric use:

$$K_{//} = C_{//}\frac{(1-f)^3}{f^2} \quad (3)$$

where $C_{//}$ for 0° and 90° directions of the twill fabrics are given in Table 2. To calculate out-of plane permeability (if needed) use the formulae of Gebart:

3

IDC, Unit 5, Processing Simulation and Control in Composite Manufacture, AENGM0019, September 2018.

$$K_{\perp} = C_{\perp}\left(\sqrt{\frac{f^{max}}{f}}-1\right)^{5/2} R^2 \tag{4}$$

Assign thickness, porosity and a fabric with the appropriate permeability to each zone in the model. Permeability of sheared preform can be estimated using approach of Demaria et al [3] (please note, that the model is not fully validated yet):

$$K_2(\alpha) = \frac{K_1(\alpha=0)}{cos(\alpha)}\left(\frac{cos(\alpha)-f_0}{1-f_0}\right)F_{geo}(\alpha)^4 \tag{5}$$

$$F_{geo}(\alpha) = \frac{1-\frac{1}{cos(\pi/2-\beta_0)}+\frac{cos(\alpha)}{sin(\beta_0)}}{1-\frac{1}{cos(\pi/2-\beta_0)}+\frac{cos(\alpha)}{sin(\beta_0-\alpha)}} \qquad \beta_0 = \frac{\pi}{4}$$

where α is the shear angle, β_0 - is the initial orientation of the principal axis with respect to the warp direction, the directions 1 is at an angle of $\alpha/2$ to the warp direction, and the directions 2 is at an angle of $(\alpha+\pi)/2$ to the warp direction. Based on Quickform simulations assign representative shear angle and fibre volume fraction to each of the zones.

Use the approximation Gutowski to assess the preform compressibility:

$$\sigma(f) = \sigma_A \frac{\sqrt{f/f^0}-1}{\left(\sqrt{f^{\lim}/f}-1\right)^4} \tag{6}$$

Table 4: Properties of biaxial carbon twill preform

Property	Value
The areal density (ply mass/surface area) of the fabric, g/m^2	370
The density of carbon fibres, g/cm^3	1.78
Initial fibre volume fraction	40%
Maximum practically achievable fibre volume fraction, $f^{\lim}$	70 %
Maximum theoretically achievable fibre volume fraction, f^{max}	91%
Diameter of carbon fibres	7 µm
σ_A coefficient in the Gutowski approximation of fabric compressibility, Pa	1.1 Pa
$C_{//}$, Coefficient in the estimation of permeability, m^2	$0.82*10^{-10}$
$C_{\perp}$, Coefficient in the estimation of permeability by Gebart through thickness	$\frac{16}{9\pi\sqrt{6}}$

4

IDC, Unit 5, Processing Simulation and Control in Composite Manufacture, AENGM0019, September 2018.

[1] S.G. Hancock, K.D. Potter, The use of kinematic drape modelling to inform the hand lay-up of complex composite components using woven reinforcements, Composites Part A: Applied Science and Manufacturing, 37, 3, 413-422, 2006

[2] Bickerton S., Simasek P., Guglielmi S.E., Advani S.G. Investigation of draping and its effects on the mold filling process during manufacturing of a compound curved composite part, Composites Pun *A* 28A (1997) 801-816

[3] Demaria, C., Ruiz, E., & Trochu, F. (2007). In-plane anisotropic permeability characterization of deformed woven fabrics by unidirectional injection. Part II: Prediction model and numerical simulations. *Polymer Composites*,*28*(6), 812-827.

[4] Lionetto et al, Effect of binder powders added to carbon reinforcement on the chemorheology of an epoxy resin for composites, Composites Part B 112(2017) 243-250.

Undergraduate assignment- University of Plymouth

School of Engineering - Plymouth University

COMPOSITES WITH PLYMOUTH UNIVERSITY

MATS 348 Composites Engineering Academic Year 2017/18 **Spring Semester 2018**

Three samples of marked coursework (one each of good, average and poor) are normally copied for the module quality records. These may subsequently be made available to external assessment teams for higher education quality assurance or professional accreditation. For this module, it is assumed that you give permission for your work to be archived for this purpose unless you include a letter with your submission stating that you withhold permission and stating your reasons (e.g. the data used has been released by a company with which you are associated).

The aim of this module is "to integrate the input from the two associated modules [MATS347 and MFRG311] with hands-on experience of handling these materials and structures from design through manufacture to testing. All processes should be logged as in a quality system". You are required to keep a logbook throughout this assignment to document all stages of the development and this should be available for review by staff teaching the course during timetabled periods. The assignment has been redefined to provide formative feedback and hence reduce your assessment load, and with all marks assigned to the final report/associated logbook. The component is simply a vehicle for your critical thinking! Marks are awarded when the product performance closely aligns with the initial specification and/or theoretical/numerical models and/or where clear understanding of reasons for "failure" are presented.

There will be **obligatory review meetings** in Brunel 007 held, at least once a week, normally on Monday at 11:00-13:00, monitored by barcode scanner.

This year, the components for consideration are:
(a) cycle brake lever, (b) long board truck bar, (c) subsea locking mechanism.

SUGGESTED MILESTONES (all at the start of the timetabled session, except for final Report submission which should adhere to normal Faculty procedures)

05 Feb 18 [individual] An *outline specification* for the component.

12 Feb 18 [individual] Undertake appropriate *design calculations* and consider the tooling/jigging and *manufacturing route*, CoSHH and *risk assessments*.

19 Feb 18 [team] Agree an *outline design*, manufacturing route and testing programme [JS away].

05 Mar 18 [team] Completion of mould tools for the component to be produced

16 Apr 18 [team] Submit a *component* for inspection/discussion with the course staff.

30 Apr 18 [team] Manufacture of *revised/further prototypes* or more extensive testing may be undertaken (this could happen in parallel with earlier work!). All mechanical testing should be complete by this date.

10 May 18 [individual] *Draft report* for discussion with course staff. The following may be used as an outline structure for the topics to be considered in the report. This is for guidance only and departures (especially additional considerations) from this format may be appropriate:

- context of the work with appropriate references,
- design calculations,
- limitations/assumptions in the design method,
- description and assessment of the manufacture,
- robustness/sensitivity of the design to manufacturing limitations,
- test procedures,
- test results and discussion of potential failure modes,
- implications of failure at this stage for the design/prototyping process,
- resources used/required for more effective development of the system, and
- future viability with comprehensive costing.

The final report should stand alone with a main [group] text of 2000 words maximum and appropriate Appendices (notably summary reports of the individual stages and agreed team procedures and analysis). You should distinguish yourself from your colleagues by literature review and critical analysis/discussion of the findings in an [individual] Appendix to the group report not exceeding 2000 words.

The *log-book* should be handed in with the report. **Deadline 3:00 PM on Thursday 17 May 2018.** Late submissions will be marked but no marks carried forward unless there are valid extenuating circumstances.

Additional guidance on the expectations for assignments can be found at these URLs:

https://www.fose1.plymouth.ac.uk/sme/MATS347/Technical_Report.htm
https://www.fose1.plymouth.ac.uk/sme/MATS347/coursework.htm
https://www.fose1.plymouth.ac.uk/sme/MATS347/honours.htm
https://www.fose1.plymouth.ac.uk/sme/MATS347/plagiarism.htm

//17MATS348cw.doc Page 1 of 1 30-08-19 23:15

[33] Material included with the kind permission of Professor John Summerscales

Home Laboratory- Queen Mary University of London

MAT5030/MTRM730 Composites

Coursework 1 – ICE COMPOSITES

Ice-composites can be made of adding fibres such as wood pulp (as in paper) to water and freeze it. Ice-composites were proposed during World War II to the British Royal Navy as a candidate material for making a huge, unsinkable aircraft carrier as the fibre reinforcement can turn brittle ice into materials with improved strength and toughness.

In this coursework you are asked to make and test ice-composites. You can make the ice composites in your home (or neighbours) freezer. Try to perform some systematic parameter variation such as changing the fibre type, fibre surfaces or surface treatments, fibre content, fibre length, fibre orientation or matrix (ice) properties etc. Whatever you can come up with. You are free to set up your own experiments and material parameters incl. different materials. Examples are cellulose from toilet paper, newspaper etc. but also synthetic fibres from textiles or hybrid combinations.

Composite behaviour should be tested against an unreinforced ice plate and tests can include a variety of mechanical and physical tests such as bending strength, toughness, impact strength, thermal conductivity etc. Try to quantify your composite parameters and properties as much as possible (so you can plot some graphs of property versus material parameter) but you should be doing all of this with simple home equipment such as weighing scales, rope, water buckets for loading, hammers, drop weights etc. or whatever you can get your hands on. The results should be presented in a report and your findings should be discussed and explained on the basis of composite theories.

The report should include:

1. Intro on ice-composites
2. Experimental section on your materials, processing and testing
3. Presenting your results and a discussion of these results
5. Conclusions
6. References

Extra marks will be given for *originality* in materials and testing.

You can work in teams of maximum two or on your own. You can choose your own partner.

Have a look at a scientific paper on composites in the literature to get an idea how a good report/paper looks like.

Coursework should be submitted on QMplus. Use correct submission point and only one submission (per group) is allowed.

Have fun!

Han Zhang

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[34] Material included with the kind permission of Dr Han Zhang

MODULAR PROGRAMME- COURSEWORK ASSESSMENT SPECIFICATION

Module Details

Module Code UFMFVL-15-M	**Run** Jan 18/19	**Module Title** Mechanics of Composites
Module Leader Ramin Amali	**Module Coordinator** Ramin Amali	**Module Tutors** Ramin Amali David Fisher
Component and Element Number B		**Weighting: (% of the Module's assessment)** 60%
Element Description COURSEWORK		**Total Assignment time** Independent study **65 Hours**

Dates

Date Issued to Students 31/01/2019	**Date to be Returned to Students** 20 working days after submission
Submission Place Blackboard	**Submission Date** 04/04/2019
	Submission Time 2.00 pm

Deliverables

Report (Microsoft Word + PDF) Files (Spreadsheet + Final Abaqus® files)

[35]

[35] Material included with the kind permission of Dr Ramin Amali

Task 1- Laminate Analysis 30%

A laminate is subjected to three forces and three moments as shown in Figure 1

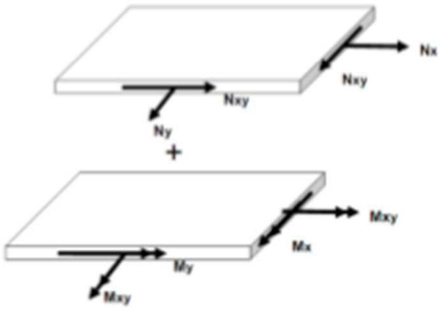

Figure 1- A laminate subjected to forces and moments

Where

- Nx = normal force resultant in the x direction (N/m)
- Ny = normal force resultant in the y direction (N/m)
- Nxy = shear force resultant (N/m)
- Mx = Bending moment resultant in the x direction (Nm/m)
- My = Bending moment resultant in the y direction (Nm/m)
- Mxy = Turning moment resultant (Nm/m)

This laminate is made of plies each having a thickness of t_k and an angle of θ_k with the x axis (global coordinate). The material properties of one ply in its principle directions are given in table 1

E_1	Longitudinal modulus of elasticity (Pa)
E_2	Transverse modulus of elasticity (Pa)
G_{12}	shear modulus (Pa)
v_{12}	Poisson's ratio
v_{21}	Poisson's ratio
α_1	Longitudinal Coefficient of thermal expansion (m/mC)
α_2	Transverse Coefficient of thermal expansion (m/mC)
β_1	Longitudinal moisture swelling coefficient (m/m/kg/kg)
β_2	Transverse moisture swelling coefficient (m/m/kg/kg)

The strength of each ply on its principle directions and also the maximum ply's shear strength are given in table 2

Table 2 -Allowable strength

$S1_{tensile}$	Pa
$S1_{compressive}$	Pa
$S2_{tensile}$	Pa
$S2_{compressive}$	Pa
$S(S_{12})$	Pa

Part A- 20%

The laminate (made of 10 lamina) is subjected to forces, moment, change of temperature ΔT and a moisture concentration of Δm. Design an interactive spreadsheets to calculate the

1. Factor of safety of each ply and the whole laminate based on maximum stress criterion
2. Factor of safety of each ply and the whole laminate based on Energy Based Interaction Theory – Tsai-Hill Criterion
3. Factor of safety of each ply and the whole laminate based on Interactive Tensor Polynomial Theory - Tsai-Wu Criterion

Part B - 10%

A laminate is made of N plies, where N is variable parameter; each ply having a thickness of $\mathbf{t_k}$ and an angle of $\boldsymbol{\theta_k}$ with the x axis (global coordinate). This laminate is subjected to forces, moments, change of temperature ΔT and a moisture concentration of Δm. Design an interactive spreadsheets to calculate the

1. Factor of safety of each ply and the whole laminate based on maximum stress criterion
2. Factor of safety of each ply and the whole laminate based on Energy Based Interaction Theory – Tsai-Hill Criterion
3. Factor of safety of each ply and the whole laminate based on Interactive Tensor Polynomial Theory - Tsai-Wu Criterion

Deliverables

A spreadsheet for the given task labelled with your name and student number

Note:

You will need this spreadsheet for the Task2.

Task 2- Design and analysis of a composite pressure vessel 70%

Introduction- filament winding

Filament winding is used for the manufacture of parts with high fibre volume fractions and controlled fibre orientation. Fibre tows are immersed in a resin bath where they are coated with low or medium molecular weight reactants. The impregnated tows are then literally wound around a mandrel (mould core) in a controlled pattern to form the shape of the part. After winding, the resin is then cured, typically using heat. The mould core may be removed or may be left as an integral component of the part.

The filament winding process was originally invented to produce missile casings, nose cones and fuselage structures, but with the passage of time industries other than defence and aerospace have discovered the strength and versatility of filament winding. Examples of products created using the process of filament winding include:

- Tubes
- Transmission poles
- Aircraft fuselages
- Gas, water, or tanks
- Cement Mixers
- Pipes

Brief

Your task is to use your laminate design spreadsheets and the Abaqus® finite element analysis software package to design a laminate layout for a pressure vessel as shown in figure 2. The pressure vessel subjected to an internal pressure of 60bar. Your final design must have a factor of safety of 1.5.

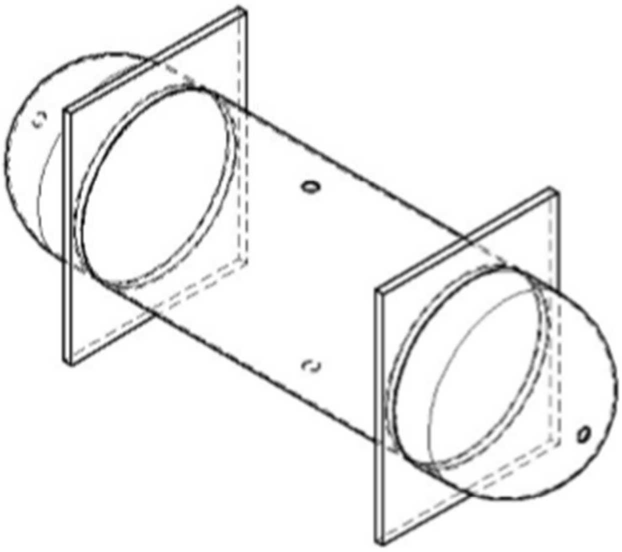

Figure 2- General layout of a composite pressure vessel subjected to internal pressure

The pressure vessel is supported by two concrete supports as shown in figure 2. The concrete supports are assumed to be rigid compared to the pressure vessel. The environmental effects of moisture may be assumed to be negligible.

There are two inlets on each spherical end cap of the pressure vessel and there are two outlets on the top and bottom of cylindrical part as presented in figures 2 and 3. Diameters of inlets and outlets are given to be 60mm.

Dimensions of the pressure vessel are given in Figure 3 and Table 3

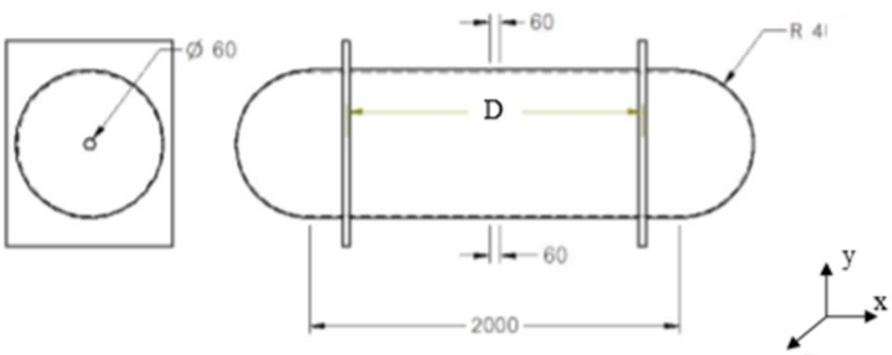

Figure 3- All Dimensions in mm

Table 3- Dimensions for the inner radius and position of supports

First Initial	R (mm)	D(mm)
A	310	1600
B	330	1600
C	350	1600
D	370	1600
E	390	1600
F	410	1600
G	430	1600
H	450	1600
I	430	1600
J	420	1500
K	390	1500
L	370	1500
M	350	1500
N	340	1500
0	320	1700
P or Q	380	1700
R	390	1700
S	420	1700
T	400	1700
U or V	410	1700
W	420	1700
X or Y or Z	430	1700

Material properties for the lamina in the principal directions are given in Tables 4 and 5.

Table 4- Lamina's properties

long. modulus E_1	120000	N/mm^2
trans. modulus E_2	8000	N/mm^2
shear modulus G_{12}	6000	N/mm^2
Poisson's ratio n_{12}	0.3	-
Density	1450	kg/m^3
Longitudinal Coefficient of thermal expansion	10	μ/C°
Transverse Coefficient of thermal expansion	30	μ/C°

Table 5- Lamina's strength

Allowable stresses:		
long. tension X_t =	1800	N/mm^2
long. comp. X_c =	1200	N/mm^2
trans.tension Y_t =	80	N/mm^2
trans. comp. Y_c =	200	N/mm^2
shear S =	150	N/mm^2

Procedure

Engineering Analysis of the pressure vessel

1. Research on filament winding method (to determine the limitation of this method and preferable angles of fibres etc.)
2. Use the theory of pressure vessels (without consideration of the pressure vessel's weight) to determine the applied longitudinal and hoop forces per unit length (Nx, Ny, Nxy, …)
3. Use your spreadsheet to determine the best layout for the applied forces- using Solver will help you significantly.
4. Use your theoretical laminate layout from step 3 to analyse the pressure vessel using Abaqus®
5. Perform a mesh study to determine the optimum size of mesh
6. If your FOS is within limit go to step 7 otherwise change the thickness or angle of fibres to achieve the given FOS

Advance Analysis

7. Investigation on design and analysis of inlet and outlets and how this effect the FoS
8. Investigation on the effect of weight of the pressure vessel on FoS
9. Investigation on environmental effect when temperature change; ΔT=20° on FoS

Note1-

You need to document every step of your work. Remember that ONLY your report will be marked.

Note2-

The output of this coursework will be a report in the style of a 10 page conference paper. Please use the provided template (Manuscript_template)

Marking scheme

Research • Literature review • Theory of pressure vessels, connectors, etc.	10%
Engineering Analysis of the pressure vessel • Use of spreadsheet • Application of Abaqus® • Application of Loads/ Boundary conditions/ Mesh study • Design Iterations • FoS	40%
Advanced Analysis • Design and analysis of the inlet and outlets • Consideration of the weight of the pressure vessel • Temperature change	15%
Documentation • Format • Structure • Referencing	5%

Deliverables

A report (MSWord +PDF) for task 2 + Final Abaqus® files

Appendix 14- Legal Advice Note

The included Legal Advice Note was prepared by Veale Wasbrough Vizards in August 2019. The provided pdf document follows this page.

Appendix 15- Example Units

The following material was developed as part of this project.

Tolerancing, Variability and Defects was written by Professor Kevin Potter. His initial slides were converted into a second version and set of handouts by Desmond He and Chiara Petrillo. The hand layup exercise was written by Dr Michael Elkington.

Production Costing was written by Professor Kevin Potter and Dr Carwyn Ward. It includes an interactive 'Virtual Composites Company' spreadsheet developed by Adam M Moss. The initial slides were converted into a second version and set of handouts by Kirk Willicombe, who also wrote a worked example for the spreadsheet.

Mechanical Properties and Testing- Anisotropic Elasticity was written by Dr Nuri Ersoy.

Standards and Certification was written by Dr Stefanos Giannis, Dr Michael Gower and Dr Graham Sims, plus NPL's Training Team, under the supervision of George Pask.

Copies are available on request.

Engineering courses joint venture

Advice note

August 2019

Con Alexander
Email: calexander@vwv.co.uk
DDI: 0117 314 5214
Reference: cxa/1u028.0662

Veale Wasbrough Vizards

1 Background

1.1 This note sets out our high level advice on the options available to formally establish a collaboration (the "**Consortium**") between the University of Bristol ("**Bristol**") and a number of other universities and other institutions which is intended to develop a course of study in engineering that can be delivered to industry on a commercial basis (the "**Programme**").

1.2 As we understand it, the key features of the Consortium are:

1.2.1 Participants taking courses on the Programme can either undertake units of study relevant to their role for CPD purposes or can choose to apply for a Masters qualification with one of the institutions and use the units as credit towards the qualification;

1.2.2 There are currently 18 institutions likely to be involved as members of the Consortium ("**Members**"), but their involvement is likely to differ in some respects.

1.2.3 Many of the Members will be Universities which are also charities, but other institutions (including some non-charitable institutions) are also likely to be Members.

1.2.4 It is likely that that a Member (a "**Lead Member**") will take responsibility for the administrative operation of the Programme.

1.2.5 The majority of the Programme content will need to be developed by the participating Members (or existing undergraduate materials will need to be suitably adapted). Members will therefore contribute material to the Consortium, together with the time and expertise of their employees.

1.2.6 Candidates' employers will be responsible for payment of the fees required in order to participate in the Programme.

1.2.7 Academics participating in the Programme (or the Member by which they are employed) will be paid by the Consortium for their teaching time.

1.2.8 The aim is that the Consortium will be self-funding in the future, with any surplus being fed back into investment in the Programme. There is also the potential for grant funding to support the establishment and development of the Programme.

1.3 We assume that the key objective in relation to the establishment of the Consortium is to identify a model that will:

1.3.1 Provide Members of the Consortium with an appropriate opportunity to participate in it, recognising that some Members will wish to participate for different reasons and in different ways, with a clear articulation of the Members' respective rights and obligations.

1.3.2 Provide the Consortium with a robust and effective governance structure that will best support the effective development and delivery of the Programme.

1.3.3 Provide the Consortium with the ability to use Consortium Members' background and foreground intellectual property rights ("**IPR**"), while protecting the IPR to ensure that it is not used for commercial purposes.

1.3.4 Enable new Members to join the Consortium and existing Members to withdraw from it.

1.3.5 Cater for the termination of the Consortium if it is no longer required.

1.3.6 Be consistent with the legal and regulatory obligations of the Consortium Members, particularly as regards those Members with charitable status (such as Universities, which are generally exempt charities). These will also include any EU procurement and State aid obligations.

1.4 In preparing this note, we have assumed that the overriding objective of the Consortium is to deliver education to individuals drawn from industry via the Programme and that, while this may also benefit those individuals' employers (by enhancing their employees' skills and knowledge), those employers will be drawn from across the engineering industry and any benefit to them is not intended to be any more than incidental to the delivery of education to individual participants.

1.5 This is an important point because we understand that the majority of Members of the Consortium will, like Bristol, be Universities with charitable status. Specific legal rules apply to charities in terms of the activities they are able to carry out and support, particularly as regards the application of their funds and other assets such as IPR. We comment on this aspect in more detail in paragraph 8 below.

2 Governance models

2.1 There are essentially two governance models that can be used to establish the Consortium. These are:

2.1.1 A contractual collaboration (see paragraph 3 below).

2.1.2 A joint venture ("**JV**") vehicle model (involving a separate legal incorporated limited liability company or limited liability partnership) (see paragraph 4 below).

2.2 We have set out below the key features of each governance model.

3 Contractual collaboration

3.1 The Consortium could be structured as a contract (a "**Consortium Agreement**") between its Members. Subject to our comments at paragraph 3.11 below, this is essentially a purely contractual arrangement.

3.2 As a contractual collaboration, the Consortium itself would have no legal existence in its own right and would only be capable of engaging with third parties (e.g. Programme participants, industry employers etc.) via one or more of the Consortium Members themselves.

3.3 This has a number of implications:

3.3.1 An application for funding for Consortium activities by a Member may have an impact on the Member's ability to apply for funding (e.g. from the same source) for its own activities.

3.3.2 An application by a Member for funding may not be able to capitalise fully on the strength in the Programme and Consortium brand.

3.3.3 Where Consortium funding is received by a Member, additional arrangements would be necessary for the funding to be spent by the other Members in order to deliver the Programme. Cross-invoicing arrangements may be required.

3.3.4 Other Consortium assets (e.g. IPR) could also only be held by one or more of the Members, with access granted to the other Members to enable them to be used to deliver the Programme.

3.3.5 Consortium contracts could only be entered into by one or more of the Members. This means that primary liability under a contract will lie with the Member which has entered into it, unless there are any additional arrangements between it and the other Members to meet any liabilities which do arise (e.g. by way of an indemnity). Typically, the most practical approach is likely to be that one Member acts as the "lead" Member for this purpose.

3.3.6 A Member's own requirements in relation to e.g. authorising and signing contracts and procurement processes in relation to the grant of a contract may have an impact on the efficient and effective delivery of the Consortium's activities.

3.3.7 Payments to or by the Members in respect of Consortium activities may have VAT implications for the individual Members.

3.4 Given the potential issues identified above in relation to a contractual collaboration, there are a number of areas which a Consortium Agreement should expressly address in order to mitigate against risks and assure the efficiency of the structure.

3.5 In particular, the Consortium Agreement should articulate the rights and obligations of the Members in relation to the Consortium (including their obligations in terms of its funding and their entitlement to any surpluses). It would be possible for the Consortium Agreement to establish different levels of participation in the Consortium for different categories of Member, depending on the scope of the rights and the obligations (in terms of e.g. the staff time, IPR etc. they will contribute to the Consortium) they wish to acquire. This could create a structure within which there is a group of "full" Members with greater rights (and corresponding obligations) in relation to the Consortium, with a category of "associate" Members who are obliged to contribute less to the Consortium but have a lower level of corresponding obligation and fewer rights. Other categories could also be provided for.

3.6 Where there are different levels of participation by different categories of Members, it may be desirable for their respective rights and obligations to be set out in separate category specific contracts which are supplemental to the Consortium Agreement.

3.7 The Consortium Agreement should also articulate the governance arrangements for both the Programme and the Consortium. With a potentially significant number of Members participating in the Consortium, it will be important to ensure that there is a sufficiently streamlined and effective governance structure for both of these aspects. This could be by e.g. establishing a Consortium board (the "**Board**") made up of a group of individuals nominated by the Members with delegated authority to make a range of decisions, but within a range of e.g. 5 to 10 individuals in order to facilitate effective decision-making.

3.8 If there are different categories of Member, one option would be for the "full" Members to appoint the members of the Board, perhaps with a minority being appointed by the "associate" Members. There are a number of different options that could however be adopted; the key point will be striking a balance between fair representation and governance efficiency. It will also be very important to articulate clearly the range of delegated powers exercisable by the Board (with a range of appropriate authority levels).

3.9 The following issues should also be addressed:

3.9.1 The Consortium Agreement should regulate how and who should award and enter into contracts for the delivery of Consortium activities taking into account the specific requirements of the Members in relation to EU procurement, contract authorisation and signing. On the assumption that a Lead Member takes responsibility for the administration of the Programme and it may be that the Lead Member is also best placed to act as the "lead" in terms of contracting for the delivery of Consortium activities. If so, the other Members of the Consortium would likely need to e.g. indemnify the Lead Member against any liabilities it incurs when acting as the lead in relation to contracts.

3.9.2 In general, the Consortium Agreement should in any event specifically address how liabilities as between the Members should be apportioned. For example, a Member which enters into a contract to enable the delivery of a Consortium activity should in our view have a clear entitlement to the relevant funding required to make payments under it and to an indemnity from the other Members in relation to any liabilities which arise under it

3.9.3 The Consortium Agreement should also regulate how funding for Consortium activities should be applied for and by whom. The Consortium Agreement should also regulate the entitlement of the Members to Consortium funding, so that there is a clearly described mechanism for a Member's Consortium costs and expenses to be met and a clear basis on which any liability to VAT can be assessed (and please see our comments on VAT below).

3.9.4 The Consortium Agreement should regulate the ownership and use of Consortium assets (including any IPR - please see our more detailed comments in relation to this aspect in paragraph 9 below). Again, it may be that the Lead Member should hold Consortium assets on behalf of the other Members, subject to any restrictions set out in the Consortium Agreement.

3.9.5 The Consortium Agreement should contain clear provisions for a Member to exit or enter the Consortium, with appropriate notice and clear provisions in relation to a departing Member's entitlement to Consortium assets.

3.9.6 The Consortium Agreement could also cater for the termination of the Consortium as a whole and how any Consortium assets should be dealt with on termination.

3.9.7 The Consortium Agreement should include some clear provisions confirming that the Consortium is not a legal partnership (for the reasons explained at paragraph 3.11 below).

3.9.8 The Consortium Agreement should set out an agreed list of any decisions which can only be taken by the Consortium Board with the consent of the Members.

3.9.9 The Members' voting rights in relation to the Consortium, including any provisions which require unanimity rather than a majority vote (where e.g. there is some major change proposed to the structure of the Consortium or a proposal to admit an additional Member) should also be set out.

3.9.10 The Consortium Agreement could also potentially cater for the Members delegating arrangements for signing documents on a single, standard basis. This would depend on the constitutional arrangements of each of the Members and their internal rules on delegated authority.

3.9.11 The terms of any grant funding will require the Lead Member of the Consortium to ensure that the grant funding does not give rise to any State aid issues (where State aid is relevant) so we would expect the Consortium Agreement to include provisions regarding the provision of information in connection with State aid enquiries and to ensure that Members have appropriate monitoring and audit arrangements in place.

3.10 Provisions of this kind will in our view mitigate some of the legal risks associated with the contractual collaboration model mentioned above. However, they will not make any material change to the fundamental issues in relation to asset-holding, primary liability for contracts and applications for funding and will not affect a Member's own requirements in relation to the authorisation and signing of contracts and procurement. These are factors that derive from the Consortium having no legal existence separate from its Members.

3.11 We should add that in certain circumstances, a contractual collaboration can constitute a legal partnership. A legal partnership has a number of implications, of which the most important are that all partners are generally both jointly and individually liable for the debts and other liabilities of the partnership and that one partner has the ability to bind its other partners. Clearly, the implications for an individual partner in terms of liability are potentially significant, notwithstanding that a well drafted partnership agreement will generally adjust liabilities and set authority levels to mitigate risk for the partners.

3.12 The test of whether a legal partnership exists is a mixed question of fact and law. But the key question is whether the Members of the Consortium intend to work together with a view to making a profit. Our view is that this is unlikely given the overriding objective of establishing the Consortium and the charitable status of many of the Members.

3.13 In our view, therefore, it should be possible to ensure that the Consortium is not established or operated as a legal partnership. But only a Court could decide this conclusively and there is always a risk (albeit in our view a low risk which can be mitigated against) that a third party with a potential claim could seek to bring it on the basis that all Members are partners in a legal partnership and jointly and severally liable in respect of the claim.

4 Joint venture vehicle

4.1 Setting up a separate legal entity (a "**Newco**") as a vehicle for a JV collaboration is an established alternative to a contractual collaboration.

4.2 This model differs from the contractual collaboration model because the Consortium would be established via a separate legal entity established solely for that purpose and which will be owned by the some or all of the Members.

4.3 A JV vehicle can be established as a limited liability company (an "**LLC**") or as a limited liability partnership (an "**LLP**").

LLC

4.4 An LLC is very often used as the vehicle for carrying out a collaboration, particularly on a JV basis. An LLC is established with one or more members who own and control the LLC, which is under the day to day control of a board of directors. An LLC can be established as a company limited by shares or by guarantee. An LLC's limited liability and incorporated status will generally protect both its members and directors from exposure to liabilities incurred by the LLC. An LLC can have charitable status.

4.5 Investment in an LLC which is established as a company limited by shares is possible by way of equity (i.e. the shareholders subscribe for their shares and the price they pay is used to fund the LLC's activities) or by way of loan (or a combination of loan and equity finance). Funding can also be raised by way of grant. An LLC established as a company limited by guarantee can only raise funds by way of loan and grant.

4.6 Using an LLC limited by shares to establish Newco would enable its members to participate in any profits generated by it in proportion to their percentage shareholdings, with a right to receive any dividends declared out of its profits. We have however assumed that it is not intended that funding should be raised by way of equity (on the basis that funding will be obtained by way of grant and fees paid by employers) nor that there will be any requirement to distribute profit to the Members (on the basis that any profits will be re-invested in the Programme). For these reasons, we have assumed that, if Newco is established as an LLC, this should be by way of a company limited by guarantee. This would be in the line with the approach often adopted in a collaboration which is focused on educational output rather than generating a commercial profit.

4.7 An LLC is potentially liable to pay tax on its profits, unless it has charitable status and the profits are generated in the course of carrying out a trading activity which advances its charitable objects. There is further information about the tax position in paragraph 8 below.

LLP

4.8 An LLP is also sometimes used as the vehicle for establishing a collaboration, particularly on a JV basis. An LLP is established by 2 or more members who own and control the LLP, which is under the day to day control of a group of "designated members".

4.9 Investment in an LLP is possible by way of capital contribution by the LLP's members or by way of loan (or a combination of capital and loan finance). In principle, funding can also be raised by way of grant.

4.10 The members of an LLP participate in its profits in proportion to shares agreed between them, with a corresponding right to receive a proportion of the LLP's profits. Like an LLC, an LLP has a limited liability and incorporated status, which will generally protect the LLP's members from exposure to liabilities incurred by the LLP. An LLP cannot have charitable status.

4.11 The key difference between an LLP and an LLC is that an LLP is "tax transparent" i.e. its profits and losses are treated as the profits and losses of its members for tax purposes. This can be advantageous where taxable profit is generated because it can enable those of an LLP's members which are charities to take advantage of the exemptions and reliefs from tax which they are eligible for.

Our recommendation

4.12 As we have indicated, the key advantage of using an LLP to establish Newco would be its "tax transparent" status, which may allow those Members of the Consortium who are also charities to take advantage of the exemptions and reliefs from tax which they are eligible for (and assuming that if Newco is established as an LLC it does not have charitable status, which would enable it to claim exemption from tax on profits generated by a trade which promotes its charitable objects in any event).

4.13 This will however only be relevant if and to the extent that Newco generates significant taxable profits (unless Newco is a charity, any profit would need to be reinvested in the Programme after tax). On the assumption that any profit will be low, our view is that any tax advantage is likely to be outweighed by the fact that an LLC is a very familiar vehicle for establishing a JV vehicle which most Members will be familiar with in terms of participation. An LLP is likely to be less familiar and will also involve the Members in addressing their participation in the LLP in their own tax returns.

4.14 On balance, therefore, we would recommend that the new entity should be an LLC rather than an LLP, unless there is a likelihood that Newco will generate significant taxable profits and will not itself be a charity, so that the profits can be sheltered by using an LLP's tax transparent status. We have assumed in the remainder of this note that Newco should therefore be established as an LLC.

5 Newco

5.1 In relation to the Consortium, setting up Newco is likely to involve the following arrangements:

5.1.1 Newco would be co-owned by some or all of the Members of the Consortium and regulated by a set of articles of association which would give each Member equal rights in relation to it.

5.1.2 Newco would be under the day to day control of a board of directors who would act as the Consortium Board and make decisions in relation to the delivery of the Programme. The directors will owe Newco a range of duties under company law.

5.1.3 The Consortium Agreement entered into by the Members will regulate the Members' rights and liabilities in relation to Newco and also between themselves.

5.2 Newco's governance structure would reflect the arrangements the Members determine are required for the effective operation of the Consortium and delivery of the Partnership. As with a contractual collaboration, it would be possible for Newco's members to be "full" Members of the Consortium (with corresponding rights under company law in relation to it), while other "associate" Members would not be members of Newco.

5.3 Equally, Newco's articles can reflect the desired composition of the board required to make decisions in relation to the operation of the Consortium and the delivery of the Programme. As with a contractual collaboration, there are a number of different options that could be adopted in the context of Newco; the key point will again be striking a balance between fair representation and governance efficiency. It will also be very important to articulate clearly the range of delegated powers exercisable by the Board (with a range of appropriate authority levels).

5.4 The Consortium Agreement would also deal with a range of issues, including most of those identified in paragraph 3.9 above in the context of a contractual collaboration. The key provisions would be:

5.4.1 The role of Newco within the Consortium, identifying those activities that it will carry out and those activities which would continue to be carried out by collaboration between the Members themselves.

5.4.2 Provisions in relation to funding for Consortium activities (and any specific funding for Newco).

5.4.3 Provisions in relation to Consortium contracts (including those contracts that would be entered into by Newco and the procurement obligations that would attach).

5.4.4 Provisions for Newco to hold Consortium assets including e.g. IPR.

5.4.5 The Lead Member's role as the entity responsible for the administrative operation of the Programme, which it may do under a sub-contract issued by Newco (rather than, as envisaged within a contractual collaboration as lead contractor on behalf of the Consortium Members).

5.4.6 Entry to and exit from the Consortium by the Members.

5.4.7 The termination of the Consortium, including provisions for the distribution of any Consortium assets.

5.4.8 The distribution of any Consortium surpluses (including surplus profit within Newco) amongst the Members or (as we understand is the intention, their reinvestment in the Programme.

5.4.9 An agreed list of any decisions which can only be taken by the Consortium Board with the consent of the Members.

5.4.10 The Members' voting rights in relation to the Consortium, including any provisions which require unanimity rather than a majority vote (where e.g. there is some major change proposed to the structure of the Consortium or a proposal to admit an additional Member).

5.5 The key advantages of using a JV Newco as against a contractual collaboration are:

5.5.1 Newco is a legal entity in its own right which is capable of entering into contracts, incurring liabilities and holding assets independent of the Members.

5.5.2 Unless they were to provide a guarantee of Newco's liabilities (which is unlikely to be required), the Members' liabilities for contractual and other obligations taken on by Newco will in almost all cases be limited by its limited liability status.

5.5.3 This will also mean that liabilities can be dealt with as between the Members with a greater degree of clarity and equality. Instead of e.g. one Member (i.e. the Lead Member) incurring primary liabilities under Consortium contracts, Newco will take the liabilities on, with the Members' respective obligations in relation to the contracts regulated by the Consortium Agreement.

5.5.4 Using Newco is less likely to have an impact on individual Members' ability to raise grant funding.

5.5.5 It should also be possible for Newco to be given delegated authority to sign documents on a single, standard basis. This would help simplify the administration of the Consortium but would depend on the constitutional arrangements of each of the Members and their internal rules on delegated authority.

6 Specific issues

6.1 There are a number of specific issues that need to be taken into account in analysing the pros and cons of using Newco.

Procurement

6.2 The rules on procurement may be relevant to some of the Members and Newco if and to the extent that Newco were to provide services to the Members under the Consortium Agreement in exchange for e.g. any funding provided by them. The procurement rules generally apply to Universities and other state funded organisations (although some Universities have decided that they fall outside the scope of the rules).

6.3 The procurement regime would therefore potentially apply to contracts awarded by the Members to Newco, and contracts awarded by Newco. The full procurement regime applies where the total spend by a Member on a particular service from Newco over the whole of the contract term for that service exceeds the relevant threshold. At present, this threshold is £182,302 plus VAT for contracting authorities, such as Universities. There are separate rules for lower value contracts and a "lighter touch" regime for some types of services contracts with a higher threshold, for example, for the provision of teaching services. We can advise further on this if required.

6.4 To avoid the difficulties that the procurement rules would create by requiring Members to tender for services, it may be possible to structure Newco under an exemption. This would allow Members In order to meet the conditions for exemption:

6.4.1 the Members must jointly exercise over Newco a control which is similar to that which they exercise over their own departments

6.4.2 the Members should have a representative on the decision making body of NewCo

6.4.3 Newco must perform more than 80% of its activities for the Members rather than for the wider market

6.4.4 There must be no direct capital participation from other parties. This would need to be carefully considered if any of the Members are privately funded institutions.

6.5 The corollary is that Newco can only provide up to 20% of its services to third parties, such as third party employers, in order for the exemption to apply to Newco to allow the Members to procure services from it outside of the procurement rules.

6.6 We recommend that the procurement position is looked at in more detail if Newco is the preferred option in order to establish the Consortium and to see whether this will work commercially.

State aid

6.7 The State aid rules prohibit the grant of aid or any other measures which would confer upon an organisation carrying out commercial activities a benefit, which could distort or potentially distort competition in the market and has an impact on EU trade. Payments made in breach of the State aid rules are unlawful and are liable to be returned to the body which made them together with interest at the statutory rate. There is also a risk that third parties who have not received aid can bring claims for damages.

6.8 It will therefore be important to ensure that any aid received through grant funding or from Universities is structured so that it does not give rise to State aid, either at the level of the Members, Newco or the employers.

6.9 There are a number of exemptions from the State aid rules or ways in which the financial arrangements can be structured so as not to amount to aid, and which we can explore in more detail when appropriate. For example, State aid granted to Members for the provision of education and the transfer of know-how is unlikely to be caught. Members will need to ensure that employers are paying market rate for their employees to participate in the engineering courses. Careful consideration will also need to be given to the allocation of intellectual property rights in the course materials and where they are owned from a State aid perspective.

6.10 Again, we recommend that further advice is taken on the State aid position if Newco is the preferred option in order to establish the Consortium.

Employees

6.11 If Newco is established it could, as a separate legal entity, employ staff to carry out its activities. If Newco does acquire its own employees, it will need to operate PAYE and account for tax and NICs on salaries. It will also require an HR function in order to manage its employees, albeit that this service could be purchased from a University or third party.

6.12 There are however alternative approaches and it may be that Newco's requirement for the services of staff could be addressed by the supply of services of e.g. the Lead Member's staff and/or the secondment of staff by one or more of the other Members.

6.13 Again, we recommend that further advice is taken on the employment position if Newco is the preferred option in order to establish the Consortium.

VAT

6.1 We have not carried out any analysis of the VAT position in relation to the Consortium, but recommend that the position is looked at in more detail if Newco is the preferred option in order to establish the Consortium.

6.2 There would be a cost to administering and accounting for VAT in relation to Newco, although this may not be significantly higher than the total cost to the Members of administering any VAT correctly under the contractual collaboration model.

Administration

6.3 As a separate legal entity, Newco will require a degree of administration in order to ensure that it complies with company law and other relevant legal regimes:

6.3.1 Statutory books will need to be maintained and changes in Newco's directors notified to Companies House.

6.3.2 Annual accounts will need to be prepared and filed with Companies House. Newco is likely to qualify as a small company, which means that it will be permitted to file abbreviated accounts and that these accounts will not need to be audited. The criteria for being a small company are that at least two of the following factors apply to Newco:

(a) annual income of under £6.5m;

(b) assets of under £3.26m; and

(c) fewer than 50 employees.

6.3.3 Newco's directors will need to hold and minute meetings.

6.3.4 Newco will require a registered office and must use letterheads etc. that comply with company law requirements.

6.3.5 Newco will need its own bank account(s) under the control of its directors (potentially with delegated authority) and will need to issue invoices for its charges to the Members and third parties.

6.3.6 As indicated above, Newco may require additional services in respect of VAT and HR, which will carry a cost.

7 Comparative analysis

7.1 In terms of the comparative advantages and disadvantages of using Newco as against a contractual collaboration, our view is that the advantages are:

7.1.1 Using Newco will clearly meet the objective of creating a legal entity which can enter into contracts, incur liabilities and hold assets in its own right, thereby avoiding the need for one or more of the Members to fulfil this role.

7.1.2 Newco will limit the Members' liability for Consortium activities and will avoid one or more of the Lead Member or other Members from carrying primary liability for those activities.

7.1.3 Newco would be a vehicle that could be used to obtain funding in its own right, maximising the Consortium's brand and limiting the potential for Consortium applications for funding to impinge on the ability of the Members to raise funds.

7.1.1 Newco can hold and exploit Consortium assets centrally for the benefit of the Members.

7.1.2 Payments for Consortium activities carried out by Newco will be made via Newco, avoiding the cross-invoicing arrangements that may be required under a contractual collaboration.

7.2 In terms of the disadvantages:

7.2.1 The JV vehicle model will involve an additional step (in terms of establishing and operating a Newco) in comparison to a contractual collaboration.

7.2.2 This can involve a degree of additional complexity (and associated cost), although this is in our view relatively limited in practice.

7.2.3 Newco creates the potential for procurement and State aid risks to arise, albeit that the range of exemptions and de minimis reliefs that are available may mitigate any risks to an extent. Further advice is likely to be required in relation to these issues.

7.2.4 Using Newco will create additional administrative obligations (please see paragraph 6.3 for further information in relation to this) and may carry an additional cost in terms of HR, corporate governance and administering and accounting for VAT.

7.3 For these reasons, we would generally recommend using a Newco within the JV model where a collaboration involves a degree of risk none of the parties establishing the consortium wish to accept (even with the risk mitigations we have mentioned in paragraph 3.9 and 3.10 above) and the scale of the collaboration (be that in terms of funding, income, value of output etc.) justifies it. But it may be that one or more of the specific advantages mentioned in paragraph 5.5 above (including e.g. any impact on funding) will override this.

8 Newco's status

8.1 While we recommend (and have assumed) that any Newco which is used should be set up as an LLC (in order to confer limited liability on the Consortium's Members), there are some options in relation to Newco's status.

8.2 The key decision will be whether to establish Newco as a charitable or non-charitable company.

8.3 If established as a charity, Newco would in our view need to be registered with the Charity Commission and its principal charity law regulator would be the Commission. While some charities which are controlled by exempt charities such as Universities can themselves be exempt, our understanding is that not all of the Members will be charitable so that this option will not be available.

8.1 Eligibility for charitable status depends upon the scope of an entity's objects (i.e. what it is entitled to do constitutionally) and also on what it does in practice to advance those objects. In terms of the Consortium, providing education is charitable and for the public benefit. Where benefits accrue to employers then there is a risk that they receive too much "private benefit" as a consequence, which would mean that the Consortium's activities would not be charitable. However, private benefit which is reasonable and incidental to activities which are for the public benefit is acceptable. The test for what is incidental is not clearly defined, so there is the scope for particular activities which are primarily aimed at e.g. benefiting business owners to be non-charitable. This is significant because activities carried out by a charity which are non-charitable can give rise to a breach of charity law and in some cases tax liabilities.

8.2 This point is relevant to those Members which are themselves charities in any event, because any support they provide for the collaboration must advance their own charitable (and, in the case of those Members who are Universities, educational) objects.

8.3 In our view, the degree of private benefit to employers is likely to be incidental to the delivery of education, particularly because (as we assume to the be the case) all relevant employers within the engineering sector will be able to pay to allow their staff to access the

Programme. In addition, those Members which are themselves charities (including e.g. charitable Universities) will presumably have taken the view that their involvement with the Consortium will advance their own charitable educational objects without giving rise to too great a degree of private benefit (if not, there would be restrictions on their own ability to participate in the Consortium).

8.4 For these reasons, and based upon our understanding of the overriding objective in relation to the Consortium and the delivery of the Programme, our view is that Newco would be capable of being registered by the Charity Commission as a charity. The approach of the Charity Commission cannot however be guaranteed.

8.5 Subject to this, and by way of comparison, the main advantages of charitable status as against non-charitable status are:

8.5.1 Profits derived from charitable activities are free of tax. This would mean that Newco could reinvest any profits in the Programme free of tax. This factor suggests that charitable status may be preferable if Newco is likely to generate significant profits which are to be reinvested in the Programme. Please note however that if the only "full" Members of Newco are charitable, then it would be possible in principle for profits to be donated to them free of tax even if Newco is not charity, with the possibility that they may then be returned to Newco. We can advise on this possibility in more detail if that would be helpful.

8.5.2 Charitable status can better enable access to some grant funding. However, this will in our experience depend on the requirements and expectations of the funder. In Newco's case, it may be that many funders will take into account that it is owned and controlled by some Members with charitable status even if it is itself non-charitable. Subject to any specific requirements from funders for charitable status to ensure eligibility for funding, this factor is in our view neutral.

8.5.3 Charitable status will generally enable an entity to claim mandatory relief at 80% (and discretionary relief at 20%, dependent on local authority policy) from NNDR for which it is liable as the rateable occupier of property provided that the occupation is for exclusively charitable purposes. In Newco's case, we assume that the nature of its activities may mean that it is not the rateable occupier of any property for NNDR purposes in any event. If so, this factor is also in our view neutral.

8.5.4 A charity can be eligible for some exemptions and zero rating reliefs from VAT. Because we have not carried out an assessment of the activities that Newco will carry out, we do not know whether charitable status is likely to be relevant for VAT purposes. For the moment, therefore, we have assumed that this factor is therefore also neutral in terms of status.

8.5.5 If Newco were to be a charity and it shares common charitable objects with those of its Members which are Universities and they have common charitable activities, the Universities will have the flexibility to provide financial and in-kind support to Newco on a non-arm's length basis should this be required. However, it would be possible for the Universities to provide non-arm's length support to Newco even if it were non-charitable provided that the activities being funded are themselves charitable. So the flexibility for the Universities to provide non-arm's length support depends upon activities that Newco will carry out being charitable (which, as we have indicated above, is in our view likely to be the case) rather than on its status as a charity or not. In our view, this factor is also therefore neutral in terms of status.

8.6 Again by way of comparison, the main disadvantages of charitable status as against non-charitable status are:

8.6.1 A charity is subject to a charity law and regulation, which generally imposes greater legal requirements than company law and would mean that Newco is regulated by the Charity Commission. A non-charitable LLC is also easier to establish and subject to a lighter touch legal regime than a charity.

8.6.2 Establishing Newco as a charity will involve more time and complexity and will also add to the cost of establishing the Consortium. An application to the Commission can often take between 3 and 6 months to complete (sometimes longer).

8.6.3 A charitable company's directors are its charity trustees under charity law and owe a more extensive range of duties to a higher standard than the directors of a non-charitable company, with a correspondingly greater potential for personal liability in respect of breach (albeit that this risk is managed very effectively by many charities).

8.6.4 Because of the duties owed by charity trustees, there is greater scope for conflict between the duties owed by a charity's trustees and the duties and/or interests they may owe to or have in other charities including, in Newco's case, those Members which are also charitable. Such conflicts are often manageable, but they can complicate the governance position in practice.

8.7 On this basis, and on balance, our recommendation is that Newco should be established as a non-charitable company because of its greater flexibility provided there is no positive tax aspect that outweighs this.

8.8 Please note that it would also be possible to establish Newco as a "community interest company" or "CIC". A CIC is a form of company developed specifically for use by social enterprises which do not qualify for charitable status. The main advantage of using a CIC is that it has a formal "asset lock" within its articles which limits its ability to distribute assets to its members and lenders. This is seen by some funders as a recognisable "not for profit" status which may be relevant in terms of eligibility for grant funding, albeit that this is more likely in the context of funding for UK community based activities. Subject to that, there are in our view no key advantages in establishing Newco as a CIC rather than as a standard private company limited by guarantee.

9 Intellectual property considerations

9.1 We understand that that the key IPR involved as part of the Consortium will be copyright in the Programme content. There will also be trade mark and branding considerations - see paragraph 9.8 below.

9.2 The following aspects need to be carefully considered regardless of the governance model chosen:

9.2.1 to what extent will the Members need access to, or licences to use, confidential information, know-how and other IPR of the other Members, including both pre-existing IPR contributed to the Consortium (i.e. existing undergraduate course material) ("**Background IPR"**), or IPR developed in the course of the Consortium (i.e. its "**Foreground IPR"**):

(a) during the term of the Consortium; and

(b) following its termination?

9.2.2 who will own the Foreground IPR developed during the course of the Consortium?

9.2.3 who can exploit the IPR so created?; and

9.2.4 are there any restrictions on exploitation of the IPR and if so, what are they?

9.3 Therefore, for either model, the Consortium Agreement must address the fundamental issues of who owns the IPR, and what use the respective Members can make of it.

9.4 As a preliminary point, unless the IPR in the Programme content are assigned to a Member on behalf of the Consortium (or to Newco) (which will give that party legal ownership of such IPR), it will need to have licences in place. It is important to specify the type of licence (which will be dependent on what the relevant party is willing to offer). A licence can be exclusive, sole or non-exclusive:

9.4.1 An exclusive licence grants rights to the licensee to the exclusion of all others, including the licensor.

9.4.2 Under a sole licence, the licensor may exploit the rights itself but may not grant licences to any others.

9.4.3 A non-exclusive licence leaves the licensor free to exploit the rights itself and to grant licences to others.

9.5 **Background IPR:**

Contractual collaboration

9.5.1 We understand that the majority of the Programme content is to be developed by the participating Members for the purposes of the Consortium (and therefore will be Foreground IPR). However, it may be the case that existing undergraduate materials will need to be suitably adapted. Therefore, a Member will need to contribute its Background IPR. As such materials will have been developed for an independent purpose, it is unlikely to be reasonable to ask for an assignment of such Background IPR. The Consortium Agreement will need to include a licence from each Member to the other Members to use its Background IPR for the duration of the Consortium (or for the duration of that Member's participation in the Consortium) and only for the purposes of delivery of the Programme (i.e. the Members are not permitted to make any further use of such IPR outside of their involvement in the Programme). It also needs to be considered whether all Members would need such rights, or whether the Background IPR licence only need to be given to the Lead Member, or the Member responsible for the administration/delivery of the Programme.

9.5.2 The scope of use of a Member's Background IPR needs to be clearly defined in the Consortium Agreement to mitigate against the risk of a Member using it for other purposes and so that the Members are all clear as to their input and how materials will be used.

9.5.3 The Members will also need to consider what is intends to happen to such Background IPR if a Member leaves the Consortium. It may be the case that the Members (or the Lead Member) need to use it indefinitely (or at least for the remainder of an academic year whilst still delivering that aspect of the Programme). To the extent that such Background IPR is required in order to make use of the Foreground IPR (e.g. new Programme content is developed using undergraduate materials as a basis), then it is in the interests of the Consortium for Members to licence such IPR on a permanent basis - so that a Member's withdrawal does not prejudice the delivery of the Programme.

Joint venture vehicle

9.5.4 A licence of Background IPR will still be required from each Member. However, such a licence will only need to be to the Newco as that will be the legal entity responsible for the delivery of the Programme. The licence should be granted on arm's length terms as the Consortium may well continue beyond the applicable Member's interests in the joint venture vehicle.

9.6 **Foreground IPR:**

Contractual collaboration

9.6.1 The starting position is that the rights in and to Foreground IPR (i.e. the Programme content commissioned specifically for the Programme), belong to the party that created it (an "**Inventing Party"**) (see paragraph 9.7.1(f) below with regard to our comments about consultants/employees). In the case of contractual collaboration, the Inventing Party will be the relevant Member, or a relevant third party if content is commissioned to be undertaken by a party who is not part of the Consortium.

9.6.2 Unless otherwise expressly provided in the Consortium Agreement, the Consortium will not have an express right to use such content. It will also have no say as to its use (or any restrictions on use by the Inventing Party). This remains the case even if work is commissioned and paid for by a Member (on behalf of the Consortium). Therefore, it is vital that the Consortium Agreement clearly sets out the scope of use and grants rights to the other Members for the purpose of the Consortium. It is also important to include restrictions on the Inventing Party's use, so that such Member is not in a position to use the Programme content (which has been paid for by the Consortium) for a competing course. By way of an example, whilst one of the existing agreements for unit development during the pilot stage gives the Consortium wide rights to use the materials 'as it sees fit', nothing in that agreement prohibits the Inventing Party from using the materials or its own purposes (including commercial purposes). We do not recommend that this is the basis of ownership/use for Programme content going forward.

9.6.3 In terms of ownership of such Foreground IPR, and in order to protect the Consortium, the options are as follows:

(a) The Inventing Party retains ownership of the Foreground IPR, provides a licence to all the other Members to enable them to use it for the purposes of the Programme only. We would also recommend the inclusion of contractual restrictions on all Members use of such Foreground IPR (including the Inventing Party), so that none of the Members are in a position to use the Foreground IPR to develop a competing programme or otherwise use it for its own purposes (unless otherwise agreed). We would recommend an exclusive licence so that the Inventing Party is prohibited from making the Programme content available to any third party. A licence, as opposed to an assignment (see paragraph 9.6.3(b) below), gives rise to the risk that the Consortium cannot make use of such Foreground IPR if the Inventing Party leaves the Consortium (unless it is clear that the licence is to continue if this happens). In any event, the licence needs to be sufficiently clear and detailed to cover all proposed uses by the Members (but this may be difficult to ascertain at this point, and it may be the case that certain uses require the consent of the Inventing Party in the future). It will need to be considered whether all Members need a right to use the Foreground IPR for the purposes of the Programme, or whether the licence only needs to be with the Lead Member for the purposes of the delivery of the Programme.

(b) The alternative is that the Inventing Party assigns (transfers legal ownership) of the Foreground IPR to one Member (e.g. the Lead Member). This has the benefit that the Lead Member can then use such Foreground IPR without further restriction. However, in the spirit of the Consortium, you may consider including a contractual restriction so that the Lead Member is restricted from using the IPR for any other purpose. This option has the benefit that, subject to any contractual restrictions set out in the Consortium Agreement, the Lead Member is permitted to use such Foreground IPR for any purpose. If a Member withdraws from the Consortium the IPR can still be used. From a practical point of view, one party owning all Foreground IPR is likely to be easier to manage (i.e. the Lead Member can sub-licence or otherwise exploit such rights and it does not need to seek consent of the Inventing Party). The Consortium Agreement should also include a licence back to the Inventing Party (and potentially all other Members) to enable the Members to make use of such Foreground IPR as part of their respective roles in the Consortium (and, if applicable, for academic and research purposes - see paragraph 9.7.1(c) below).

9.6.4 It is important to establish whether any IPR generated during the course of the Programme will be generated by a Member independently, without recourse to any other Member. Or whether, in practice, IPR may be generated jointly. If IPR are to be generated jointly, then more complex provisions in the Consortium Agreement will need to be included. Whilst most IPR can be jointly owned, and it is often suggested that the use of this mechanism provides a simple and natural approach to sharing rights in the fruits of a collaboration, we do not recommend this. This creates an additional level of complexity and in general, only allows the co-owners to exploit the jointly held rights by agreement. In effect, no party is permitted to use such IPR for any purpose without the consent of the other parties. Considering the number of Members this likely to be unduly onerous and would prejudice the operation of the Consortium and the value of the Programme.

Joint venture vehicle

9.6.5 If Programme content is developed by an employee or a director of Newco, then it will automatically vest in Newco. However, we think this is unlikely to be the case here and it will be that Newco will commission content from a Member institution (or other third party). Newco will therefore need to enter into either a licence, or an assignment with the relevant Inventing Party, either independently or as part of the Consortium Agreement to ensure that it has all necessary rights to make use of the Foreground IPR as part of the Programme.

9.6.6 As set out above, the management of IPR and exploitation is easier if this is under the control of one party, and therefore this favours adopting the joint venture vehicle model, as one legal entity will hold all the required rights in order to facilitate the Programme. However, the same outcome can be achieved under the contractual collaboration model if there is a Lead Member who is willing to take on this role.

9.6.7 It may also be appropriate to include a 'licence-back' from the Newco to the relevant Member institutions, if the Members wish to make use of any Foreground IPR for academic and research purposes.

9.7 **IPR protection and other considerations**

9.7.1 Regardless of the governance model, in order to protect the Members and the reputation of the Programme:

(a) The Consortium Agreement will need to include promises from the Members that their respective Background IPR does not infringe the rights of any other person. The same will also be required from the Inventing Party with regard to the Foreground IPR.

(b) There needs to be a clear mechanism with regard to commissioning content. This will be dealt with under the terms of the Consortium Agreement with regard to the Members' respective contributions, but there also needs to be a clear mechanism within the Consortium Agreement if third parties are engaged. This is so that Programme IPR sits with the Consortium (either by a Lead Member or via Newco) and such third party cannot make use of such IPR in a way that would conflict or restrict the Consortium's activities.

(c) If the Members wish to make use of the Programme IPR for academic and research purposes outside of the Programme, then this right needs to be clearly included within the Consortium Agreement. The scope and permitted uses need to be clearly defined and potentially an approval mechanism may need to be included.

(d) The Consortium Agreement also needs to make clear the Members' respective scope of use - both for the duration of the Consortium and clarity as to what the Members are to do if the Consortium is terminated. We recommend that the proposed scope of use is clearly set out at the outset, so that all Members understand how their IPR will be used. It will be very difficult to manage if each Member contributes IPR on different terms.

(e) The Members may also consider the inclusion of exclusivity provisions within the Consortium Agreement (i.e. that the Members are not permitted to enter into arrangements that would conflict or compete with the Programme). However, this needs to be considered carefully so as to not unduly restrict the activities of the Members.

(f) The Members need to be clear as to the individual that develops the Foreground IPR. If the content is developed by an employee of a Member or other institution, then unless there is an agreement to the contrary then the relevant employer will own the Foreground IPR (and the licence or assignment can take place via the Consortium Agreement). This is not the case if the Consortium engages with contractors or consultants and therefore extra steps may need to be taken to ensure that the relevant IPR sits with the correct party on behalf of the Consortium.

(g) The Members also need to consider IPR when applying for funding as the relevant funder may have conditions with regard to IPR ownership that may conflict with the terms of the Consortium Agreement.

9.8 **Branding**

9.8.1 We have assumed that the Programme will be marketed under a particular name, logo and brand. This has the potential to be a valuable IPR. The Consortium Agreement needs to clearly set out how and when this can be used, so that this is used in a consistent manner so as not to dilute the brand. In terms of ownership, we would recommend that one Member takes responsibility for this on behalf of the Consortium (for example, the Lead Member under a contractual collaboration). This party would then be in a position to register the IPR if applicable, or otherwise manage its exploitation. If a joint venture vehicle is used, then Newco would own the relevant IPR in the brand.

9.8.2 We assume that the Members would also require a right to use each other's name and logo as part of the delivery and advertising of the Programme (or that the Lead Member is permitted to do this on behalf of the Consortium). If a joint venture vehicle is used, then Newco would need a licence in order to make use of the Members' name and logo. We recommend that brand guidelines are developed and attached to the Consortium Agreement so that each Member's (or Newco's) permitted use is clearly defined.

9.9 **Termination**

9.9.1 It is in the interests of the Consortium that if an individual Member withdraws or is removed from the Consortium, then the other Members can continue to use its IPR for the purposes of the Programme. However, this may not be possible in practice e.g. if particular know-how or courses can only be delivered by that Member. In any event, the Consortium Agreement needs to clearly defined the duration of any licences.

9.9.2 If the contractual collaboration option is chosen, and a Lead Member appointed to hold all Programme IPR, then consideration needs to be given to circumstances where that Lead Member wishes to withdraw or is removed from the Consortium. A clear mechanism should be included within the Consortium Agreement to address this.

9.9.3 If the joint venture vehicle route is taken forward, the Consortium Agreement will need to identify different "exit routes", each with different consequences in terms of the vesting of any intellectual property rights.

9.10 **Data**

9.10.1 In addition, as the Consortium is likely to involve the pooling or sharing of data (for example if a participant wishes to use course credits towards a master's degree at a Member institution) the Members need to ensure that the Members put arrangements in place to ensure that they have all relevant legal grounds to share the data (particularly personal data).

9.11 **Summary**

9.11.1 Regardless of the model chosen, we recommend that the Programme IPR sits with one party (either a Lead Member under a contractual collaboration or Newco). We do not recommend joint ownership.

9.11.2 It is in the best interests of the Consortium that Programme content IPR are made available to it on an exclusive basis (either by way of an assignment of the relevant IPR to a Lead Member, or to Newco, or by way of an irrevocable exclusive licence to the Lead Member or to Newco). This prohibits the Inventing Party from making use of that material unless this has been otherwise agreed.

9.11.3 If an exclusive basis cannot be agreed, then we recommend that clear restrictions are included within the Consortium Agreement so as to protect the interests of the Consortium.

9.11.4 Any other proposed use of the content (e.g. for academic and research purposes) needs to be clearly set out in the Consortium Agreement, so that Members can make use of the Programme content as anticipated, but are not permitted to make use of it for their own commercial purposes.

VWV LLP
August 2019