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Creating an Integrated Curriculum for a STEM Discipline

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Abstract

Tertiary education in the UK for STEM subjects is facing a growing challenge to excite and motivate students with tangible and visible examples of the real life careers to which learners aspire, but which generally require budgets that are not available in a tertiary education environment. An excellent example is the Formula Student competition that is hugely popular in universities all over the world, but which, as a result of budget limitations, is not generally available to all students in all years of their course. At the same time as providing a stimulating and satisfying curriculum it is necessary to incorporate the key theories, disciplines, through appropriate processes and practices that are less exciting, but equally necessary to a successful STEM career. These issues have been addressed at Oxford Brookes University by the Department of Mechanical Engineering and Mathematical Sciences by developing an integrated first year curriculum, with explicit assessment, that has at its core a design and build project for a low temperature gamma type Stirling Engine. Typically Engineering degrees require students to gain hands on experience of manufacturing processes, previously known as EA1, and this was achieved by making static components such as clamps, screwdrivers, toolboxes, cold chisels or similar. The new project requires each student to create a dynamic product that ensures the successful transfer of manufacturing skills and processes as well as feeding all other modules in the curriculum. The result is an integrated, but explicit, curriculum that is constructively aligned to both the assessment and the role of a professional engineer. This, in turn, engenders "deep learning" and enhances the student experience and sense of achievement. The project requires that the students work in a simulated business environment where they must create a company to manufacture, market and sell the product using a suitable business model. The feedback from students to staff so far has shown that the new curriculum has created an expression of enthusiasm and satisfaction for the whole course that surpasses anything previously experienced.

1. Introduction

This paper defines the problem of engaging 1st year students from a broad range of ages and prior experience profiles in the challenging subject of Mechanical Engineering. A range of guiding principles are utilized to set the key objectives in the curriculum design and the intervention steps that help to make it work effectively. The simplicity of the low temperature, gamma configuration, Stirling Engine, is presented as the most suitable intervention and an evaluation of the student experience is given as evidence in improving the curriculum with enhanced student experience and motivation.

2. Problem definition

Engineering curricula within universities are largely dictated by accreditation requirements and, as such, inhibit the ability to innovate. Consequently, modular structures and topics have remained largely unaltered over recent years. The majority of programmes still have explicitly defined blocks of thermodynamics, stress analysis, dynamics, materials, *etc*. with each being individually assessed. This presents a paradox in the sense of engineering being seen as a fast moving contemporary subject leading to many innovations within the economy. Engineering at Oxford Brookes re-evaluated its course structures to facilitate enhanced learning by aligning programme learning outcomes with end of level outcomes and carefully positioned assessment points as illustrated in Figure 1 with a brief description of the module content below.

- **Engineering Mathematics and Modelling I (15 ECTS):** utilizes examples from engineering applications requiring students to use mathematics to model real engineering scenarios.
- **Engineering Design and Practice I (15 ECTS):** valuing first hand workshop experience it incorporates the full product development process by requiring students to draw, build, commission evaluate and market the product in the global economy.

- **Introduction to Thermo-Fluids (7.5 ECTS):** covers a range of thermodynamic and heat transfer processes that incorporate the Stirling and Carnot Cycles as the integrating knowledge essential for the Stirling Engine.
- **Introduction to Stress Analysis (7.5 ECTS):** covers the typical range of basic theories used for stress calculations, but which includes specific questions that utilize the Stirling Engine components to practice stress analysis skills and appreciate first hand how these calculations are used to influence component dimensions.
- **Introduction to Statics and Dynamics (7.5 ECTS):** takes the students through kinematics, kinetics, momentum, energy, power and efficiency that students apply to calculate performance characteristics of the engine such as speed, power and friction.
- **Introduction to Materials (7.5 ECTS):** presents metals, plastics and composites covering their applications with specific reference to suitable choices of material for each component of the Stirling Engine: both structural and thermal.

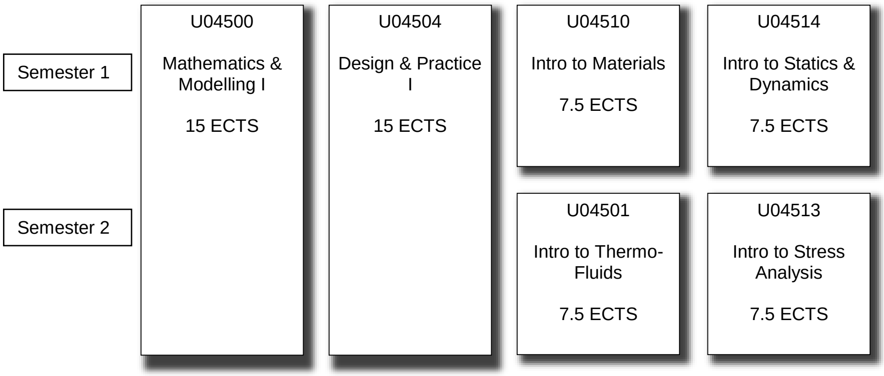


Fig. 1. Programme structure for Mechanical Engineering at Brookes with module titles.

3. Guiding Pedagogic Principles: Motivation and Guided Focus

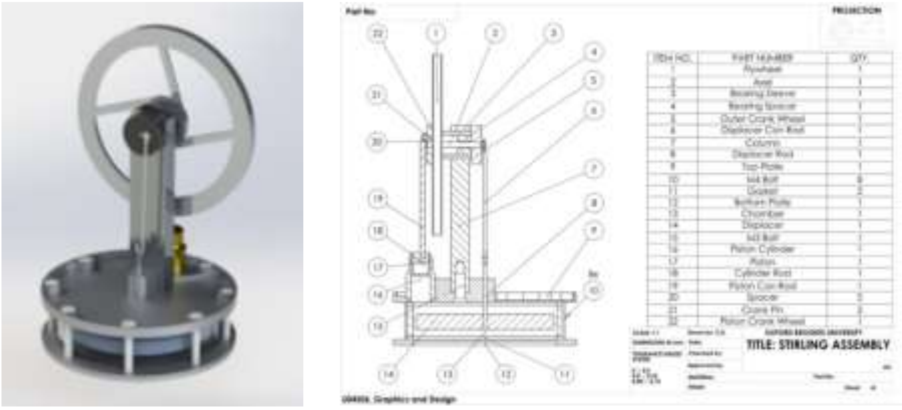
For changes to the curriculum to be effective and durable they must provide motivation to the students that fulfills their desire to follow an engineering career, actualizes learned concepts and presents a managed learning process. Learners recognize the determination and hard work necessary to be a professional engineer, and for many this can be daunting prospect given the content and cohort size. Thus, it is appropriate to evaluate intervention strategies, such as the Stirling Engine, which give the students an enhanced knowledge of the full engineering process augmenting their learning for topics seen as dry or difficult. It concludes in a device that relates all aspects of their programme with the reward of a practical experience that results in a dynamic, topical and impressive artifact. It is attractive, a technology demonstrator, and perhaps a conversation piece to engage others!

Throughout the delivery of the programme, staff use the actual components and processes as topic matter in class discussion. This engagement and the use of discursive exchange facilitate an enjoyable experience and invigorating supplement to the hands-on elements that the students already find inspirational. By repeatedly returning to the Stirling Engine, it provides a focus that enables students to appreciate the different, integrated, aspects. For example, with each topic covered, students see how each aspect relates to the engine; and, invariably draw in other topics constructively aligned to the programme learning outcomes. The engine is an excellent dynamic learning tool, however, it is deliberately designed not to be optimized in all aspects of its performance, but considered a “sufficient” design to allow students to recognize deficiencies as a result of limitations such as materials, processes and time available to build the engine. As a result, students achieve satisfaction discussing and suggesting improvements to the design taking the project outside the classroom and beyond the expected contact hours. As a result of the evaluation and review, by following this approach, students are able to reflect and constructively criticize their experience and propose changes to design & manufacture and explore modelling enhancements in other modules quantifying benefits to their design changes.

4. Intervention Strategy

The Stirling Engine, Figure 2, is based on a modified Carnot cycle and was first implemented as a practical engine, competing with the steam engine, by the Rev. Robert Stirling in 1816 [1]. As an engine it was efficient, but unreliable and the steam engine superseded it due to the power output available and a plentiful supply of coal. In recent years, however, the Stirling Engine has come back into vogue because it is an external heat engine that can use freely available sources of energy rather than carrying its own fuel, *e.g.* utilization of solar energy. The selection of this device as the central theme on which to deliver a comprehensive, but explicit engineering, curriculum was based around the following seven key features:

- **Inspirational**: The concept of extracting energy from freely available heat sources is inspirational because it unites the current, and critical, need to use, for example, renewable resources with established engineering technology. At the same time, there are challenges to be overcome that require a sound understanding of Level 4 curriculum that are explicitly taught, assessed and then incorporated into an engineering delivery, for example, the holistic approach required in marketing the device to make it commercial relevant.
- **Dynamic**: One of the anecdotal features that characterize student interest and enthusiasm is an end result/product that is dynamic and moves in the literal sense and consequently is reflected in the curriculum. Anything that moves is generally more interesting than a stationary object or device because movement catches the eye, the imagination and the interest of the beholder.
- **Explicit and holistic**: through the application of the engineering process students are asked to mirror the role of the professional engineer within their curriculum and assessment. Individual aspects and elements of engineering theory and technology are delivered explicitly using the common example of the Stirling Engine that each student is making so they are investing in the outcome by virtue of the physical effort and activity that they engage in during “lab day” manufacturing process. Since modules in the curriculum also require the student to consider performance, marketing and project management as well as analysis and production, the students are holistically engaged in the entire process.
- **Safe**: There are three common configurations for a Stirling Engine known as the alpha, beta and gamma configurations. The alpha configuration uses two separate pistons and cylinders usually at ninety degrees to one another while the beta configuration uses two pistons that share the same in-line cylinder [2]. Both the alpha and beta configurations have heat regenerator in series with the pistons and often require a heat source of sufficient strength that combustible fuel is required as the energy source. The gamma configuration uses two cylinders and pistons connected in parallel, but not aligned as in the beta configuration, and will work from a much lower temperature heat source input, typically boiling water. While boiling water can still cause scalding and burns it is very much safer than anything requiring a naked flame. This safety feature was a primary factor in the choice of engine configuration.
- **Materials selection**: This process plays such an important part of the success of modern engine that there are numerous opportunities for students to use research methods so that students have the opportunity to progress numerous improvement ideas and concepts that can be evaluated and reported on as part of the aligned assessment.
- **Design and manufacturing principles**: delivered and taught as part of a ‘live’ project which draws on the engagement the students feel through the time and labour invested. An incomplete or inadequate bill of materials or a poorly dimensioned drawing from which to manufacture a component is very much more obvious to the end user, who in this case are one and the same, so the student appreciates and engages with the process as a result.
- **Management and product development**: delivered and run in small groups who, in competition with other groups, have to consider and select the best way to manufacture and assemble an economic batch quantity of the Stirling Engines. This completes the overall engineering process by ensuring that student are aware of the need to make a profit in their ‘business’ and ensures that many of the more challenging learning outcomes from UK-SPEC are engaged with and achieved at Level 4.



(a) **(b)**

Fig. 2. Stirling Engine: (a) rendered image; and (b) sectioned assembly with list of parts.

The theoretical principles of the Stirling Engine are shown in Figure 3 and a more detailed explanation can be found in [3]. In essence, the piston is compressing the air in the cylinder by virtue of the kinetic energy transferred to it from the spin of the flywheel. The act of work being transferred into the system by compression causes an increase in pressure creating a cycle for continued motion.

5. Evaluation

An evaluation of 1st year students was undertaken using a sample of 50 students from a cohort of 130 with the results shown in Figure 4 with a score of 10 being most favourable and 1 least favourable. In addition to these quantitative results qualitative feedback statements were collected as part of the same survey. The question asked were: (1) The timetable, organization of the week, lectures then problem sessions, lab day on Friday; (2) Lab day, it's fun you are learning well vs it's not much fun, you're not learning much; (3) The analytic subjects are good, I am learning and teaching is good vs I'm getting left behind and not coping; (4) I know what is expected of me and I know what I've got to do in order to do well vs I don't know what is expected of me and I don't know what I've got to do in order to well; and, (5) I feel I'm really getting to understand what engineering is all about vs I don't feel that I understand what engineering is all about.

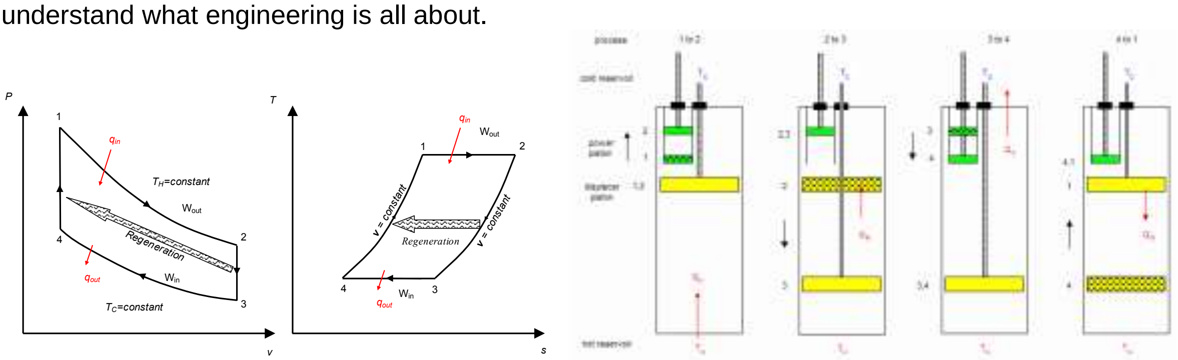


Fig. 3. Mechanical motion and thermodynamic cycles in four phases [3].

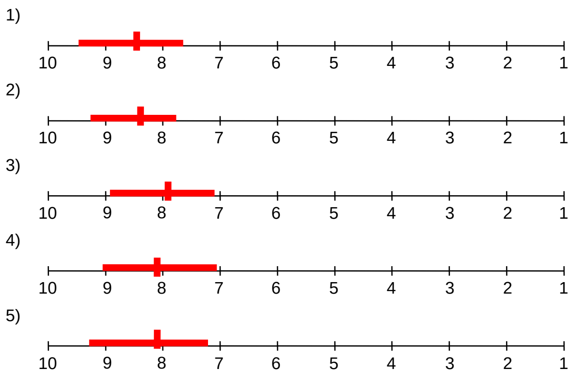


Fig. 4. Survey mean responses with upper & lower values represented by the width of the bars

Best things about the programme: *"Practical sessions (Fridays)"; "Friday sessions so far have been great"; "The thing I like best about the course so far is the practical learning and making of the Stirling Engine parts in the workshop"; The lab sessions have been enjoyable and a good learning opportunity"; and, "Lab day is very interactive, gets students working and building a good understanding of engineering"*

Things to improve about the programme: *"The things I think could be improved are timetabling in that things are too spaced out"; "More practical hands on experience"; "Long breaks between lectures means having to wait around"; "The thing I think that could be improved is the timetabling"; "Some labs could be more interactive, e.g. welding demo"; and, "Change the lab days to Mondays, Fridays are very long and hard and I feel that more students would be awake and more focused."*

6. Conclusions

The new programme structure is simpler and easier to understand for students new to the course. The evaluation feedback from students clearly shows that they appreciate the practical sessions and see their worth as part of an integrated engineering degree programme. The Stirling Engine project gives focus to their interest and improves their aptitude in standard syllabus topics resulting in an outstanding student experience that they clearly enjoy and which they can identify as helping to make learning easier and more enjoyable. The incorporation of an aligned, integrated, curriculum with explicit assessment strategy allied to engineering practice has been very successful in motivating students studying on the programme.

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