EU-OPTIMUS – A CASE STUDY OF A HOLISTIC SYSTEMS-APPROACH PEDAGOGY IN TECHNOLOGY EDUCATION

Ciara AHERN[1] and Mark McGRATH[2]
[1]Dublin Energy Lab, Dublin Institute of Technology, Ireland
[2]Dublin Institute of Technology, Ireland

ABSTRACT

Engineers and product designers are concerned with the design, development, implementation and operation of a wide range of systems. If a system is to perform optimally, all of the component parts must communicate and cooperate effectively. Technologists must therefore have an appreciation for both, the functionality of a single component of that system and the interoperability, or impact of that component within the context of the system. Scientific first principles underpin all aspects of technical education. The application of scientific knowledge at component level impacts at system level. Practical or laboratory-based activity has long been used as a complimentary pedagogy to that of traditional lectures. Laboratory offerings are conventionally conducted on a single piece of apparatus or at component level, rather than at a system level. Interfaces which help convey scientific principles in action, within the context of a system, must thus be regarded as a demarcation in technical education delivery.

This paper outlines the novel pedagogies developed by a UNESCO award winning European training initiative which created both hard and soft vehicles for learning, for level 5 learners on the European Qualification Framework. The paper describes an authentic systems-based laboratory interface to aid the lecturer in the dissemination of scientific principles, within the context of a system; as well as novel instructional modes designed to improve the soft skills of the learner. The paper further outlines, how the pedagogies developed, can be implemented within the learning curricula of higher level programmes within the wider engineering and product design community.

Keywords: Systematic learning, systematic knowledge, systems approach

1 INTRODUCTION

Williams discusses how, in technology, to prepare technologists at all levels from engineers to craftsmen, how the methodologies employed in teaching, and the consequent processes employed by the students in learning, should be derived from the <u>practice</u> of the discipline [1]

Scientific first principles from mechanics, thermodynamics to fluid dynamics etc., hence referred to as ‘scientific knowledge’, are the fundamentals around which engineering and product design curricula are shaped. Irrespective of which domain of engineering or product design the learner occupies, they require an appreciation of the fundamentals.

Hennessy and McCormick found learners to have difficulty operating with ‘decontextualised knowledge’; in using cognitive and conceptual scientific knowledge, acquired in formal subject areas, to solve problems [2]. In order to contextualise formal scientific knowledge for the learner, Layton discusses how, conceptual knowledge needs to be reconstructed, integrated and contextualised for practical action in everyday life [3]. Thus, to assist the learner join conceptual and procedural knowledge - both thought and action - empirical learning, through the medium of laboratory based interfaces is employed as part of the overall pedagogic strategy in technology education [1,4].

Engineers and product designers encounter systems and the components which make up that system be they hard/soft or a combination of both, on many levels during their daily activities. A system is the sum of its components. From the light switch to the lighting system, from the robotic arm to the production line and from the timeclock to the heating system; if the system is to operate at optimal levels, all of its component parts must communicate and cooperate optimally with one another.

Engineers and product designers must thus have an appreciation for both, the functionality of a single component comprising the system, and the interoperability or impact of that component within the context of the system.
Inherent in the adjustment of a system component is the application of a scientific principle; the adjustment of a component is a means by which the system state is regulated e.g. increasing pressure or volumetric flow rates within an energy-flow system.
Systems-based interfaces, facilitate the lecturer in promoting a 'whole' system, holistic, pedagogic approach to system design and operation [4,5]. Authentic interfaces which help contextualise knowledge within the context of a system are a demarcation from the product or component-based interfaces traditionally found in engineering and product design laboratories.
Sageev and Romanowski found a direct correlation between the amount of Technical Communication (TC) instruction and career advancement of the technologist. Moreover, the authors found engineering students to be insufficiently prepared for the job-related communication demands they face in the workplace. Sageev and Romanowski concluded, in order to reinforce the TC skills of the technologist, that educators needed to develop new TC instruction modes and options, coordinated within engineering courses, that give students more opportunities for practice and feedback—both written and oral [6].
This paper outlines the novel pedagogies developed by the EU-OPTIMUS training initiative which created both hard and soft vehicles of learning for level 5 learners on the European Qualification Framework (EQF). The paper describes an authentic systems-based laboratory interface, designed to facilitate the lecturer, in the dissemination of relatively complex scientific principles, within the context of a system, to EQF level 5 learners; as well as novel instructional modes designed to improve the soft skills of the level 5 learner. The paper further outlines, how the vehicles for learning developed, can be adopted within the learning curricula of higher level programmes within the wider product design and engineering community.

2 EU-OPTIMUS – A Case Study

2.1 Background
A gap in skills relating to the plumbing craftsman has been identified as a 'major cause' of poorly performing heating systems across Europe [7,8]. The EU Leonardo da Vinci Lifelong Learning programme funded the EU-OPTIMUS (http://eu-optimus.eu/) project [9] which was tasked with designing a bespoke Continual Professional Development (CPD) course to address the identified skills shortage (both hard and soft).

2.2 Pedagogical Approach
The pedagogical approach of the EU-OPTIMUS course has been modified to suit the aptitude level of learner which, for craft curricula, is currently EFQ Level 5. The novelty of the course lies in its use of collective pedagogical approaches to propagate the fundamentals of sustainable system design (and indirectly the inherent scientific principles) in an intelligible and coherent manner for the apprentice student. The overarching course aim is to a) train the craftsman to become more conscientious of the energy efficiency of the heating system as an entity and b) increase their level of social responsibility with respect to the effective promotion of upgrade measures to society at large.

2.3 Teaching Media
EU-OPTIMUS, through academic and industry collaboration, designed an innovative, realistically detailed model of a heating system wherein scientific principles, and the interoperability of system components (and ultimately their effect on energy consumption of the system) are demonstrated to the learner. The rig (Figure 1) is designed to allow the trainer to visually link theoretical scientific principles to practical outcomes through demonstrations and hands-on practical exercises completed by the learner. Moreover, the initiative created audit templates to aid the craftsperson in applying a systems approach to heating system optimisation where none previously existed and which past research [10] has identified as necessary for successful energy management of domestic heating systems. Furthermore the initiative created sample business contracts and video material complete with role play scripts between the end-user and craftsman to assist the learner in improving their soft skills and promoting optimisation measures in an effective, professional and businesslike manner.

2.4 Teaching Pedagogy

The teaching pedagogy aims to maximise learning efficiency from closely linking theory to practical (experimental) outcomes through hands-on learning processes undertaken by the learner. The learner thus builds up their knowledge base through concrete experiences with physical and realistic system components that they can manipulate. The learner thereby develops concepts that, with feedback and instruction, aggregate into more systematic knowledge.

2.5 Learning Outcomes & Assessment Methodologies

The EU-OPTIMUS initiative did not set out explicit Learning Outcomes (LO's) in any of the published material. A snapshot of some of the LO's and design principles implicit in the course material has been formulated by the author (see Table 1). Also included in Table 1 are suggested means by which these could be delivered and assessed. The system rig enables the lecturer to demonstrate relatively complex scientific principles relating to the design of the 'system' to the level 5 learner, without the learner being required to fully appreciate the underlying mathematical principles (more appropriate to higher levels of technical education) first hand. Rather the level 5 learner gains an increased comprehension, on a macro level, for the principle inherent in phenomena, indirectly, through the physical application of the principle on the system rig (See Figure 1).

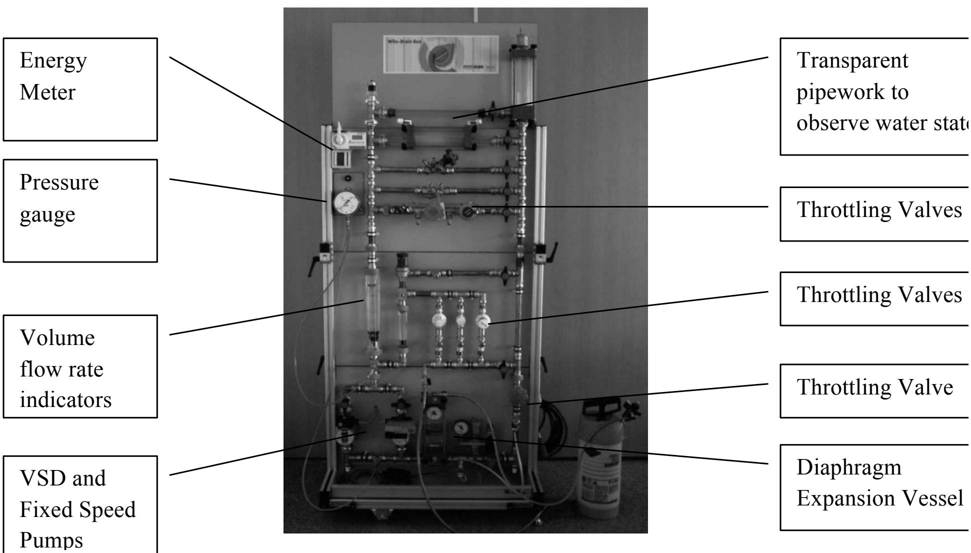

Figure 1. EU-Optimus Training Rig *Source: EU-Optimus*

It is essential that the assessment strategies are appropriately mapped to the LO's and that the assessment method is appropriate to the nature and level of the expected learning. It is therefore appropriate that the Level 5 learner be assessed on a macro level only. As an example, if we examine learning outcome (c) or Boyles Law (PV=nRT) as a case in point (see Table 1). The manifestation of this law in a heating system relates to the presence of air in that system. The component by which pressure is applied to the volume of water in a heating system is via the diaphragm expansion vessel (see Figure 2). Learners are required to outline the operation of this vessel and its influence on the system. In summary, they are required to describe the manifestation of the law rather than the law itself. Comprehension and knowledge of the scientific principle is thereby indirectly assessed. With reference to Blooms Taxonomy of Learning [11] and as outlined in Figure 2; level 5 learners apply scientific principles indirectly through the manipulation, modification, regulation and operation of the various system components (inputs). The learner records the outputs or manifestations resulting from the adjustment of a single component, thereby discovering the intrinsic relationship between that component and the overall system. It is by these means that the teaching pedagogy builds the systematic knowledge base of the learner. Assessment methods ensure that the learner can demonstrate an appropriate understanding of the relationship experienced or observed.

As stated by Gotel et al. [7] agreed requirements are the result of content transformations, e.g. an interview recording transcribed into an interview summary, which is further used to derive use cases. Thereby, information may get lost. Gotel et al. conclude that "*storing, using and maintaining extensive media-rich materials is far more costly than creating them in the first place*" [7], because relationships between transformed artifacts are not obvious later on as one might accept. These extensive media-rich materials, as also used in design thinking, require additional effort to extract their content into a machine-readable form such as semantic labelling of images using gamification [17]. As the literature conveys, traceability is applied in diverse disciplines [8], because traceability enables the reconstruction of the journey of animate and inanimate objects. However, the traceability link creators are often not the traceability link users and, therefore, see no benefit in supporting traceability [2], [18]. The same applies for the capturing of design rationales [11]. Parnas states *"documentation that is not important to its author will always be poor documentation"* [14]. Thus, immediate benefits have to be provided to design thinkers to motivate them to document [18], e.g. in software engineering traceability links can be used by the trace creators to check whether all elicited requirements are addressed by the implemented software system. Nevertheless, documenting every detail is also impossible. Parnas states that it is sufficient to document the ideal process [14]. Traceability aids to reconstruct this ideal process later on, i.e. what is important to include in the documentation and which aspects can be neglected. While design thinkers adhere to the dimensions of desirability, feasibility and viability within their process, requirement engineers adhere to the dimensions of requirements engineering as defined by Pohl [16], i.e. specification, representation and agreement. Thus, requirements have to be complete, formally represented, i.e. without ambiguities, and commonly agreed upon.

3 DOCUMENTING IN EDUCATIONAL DESIGN THINKING SETTINGS

In our research project[2] we investigated how the handover between design thinkers and engineers can be improved. Thereby, we investigated how design thinking projects are documented in educational settings. We observed that knowledge managers, who guide the students when documenting, provide a set of different tools as best practices, e.g. daily questions to be answered, design logbooks similar to diaries, digital documentation and communication platforms such as wiki systems, file shares, and templates for presentations. The students are encouraged to use these tools. Thereby, the knowledge manager predefines the structure of documentation and communication platforms only up to the project level. Providing students with a well-structured template of what to document is not sufficient, as they only will look at this template as soon as they are required to hand in their results and documentation. Thus, students are responsible to structure their documentation on their own in a manner they, as a team, are comfortable with. For example, they often use a timeline structure (e.g. week 1, week 2, etc.) or a process structure covering the design thinking process (e.g. understand, observe, point of view, etc. [15]). Thereby, the students compose documentation artifacts such as text documents, images, audio and video files, and presentation slides. When uploading these documents to the documentation platform, they do not further comment or annotate these documents. Especially in case of images the missing comments and annotations lead to the situation that the artifacts' content is undiscoverable and cannot be distinguished without looking at them individually later on. During our observations, we further observed that students always document before presentation milestones and at the end of the project, although they are encouraged to document along their process. Thereby, they present their progress several times during the project. The students mainly focus on generating insights, findings, and concepts instead of documenting them. Therefore, time for creating documentation is rare, which has to be considered when planning a documentation tool. Depending on their individual client, some student groups describe their ideas in more detail after the final presentation took place, e.g. in additional meetings or in more detailed project reports, if the client asks for either. However, the documentation of the project's journey is often neglected and only the final idea is described in detail. As in other domains in which traceability is used [2] and design rationales are captured [11], documenting in design thinking is considered as beneficial only for others. Thus, the students are not willing to document their design rationale or any other implicit knowledge they gathered. Especially in educational settings, documenting does not follow explicit

[2] http://www.hpi.uni-potsdam.de/giese/projekte/dtr_connecting_designing_and_engineering_activities.html (accessed Mai 2013)

impart knowledge in such diverse areas as Energy Engineering, Vibrational Systems, Data Acquisition Systems and Lean Implementation etc. The expected level of learning at level 6 and above is greater than at level 5, therefore the teaching & assessment strategies adopted would have to support this. This can be achieved through (i) Supporting documentation, (ii) Level/nature of instruction given during use, (iii) Extent of student-driven interaction (independence) facilitated, (iv) Nature of assessment, & (v) Depth of knowledge assessed. Implementation of higher levels of learning is, in the first instance, facilitated through the generation of an appropriate set of LO's. Teaching/instruction strategies and assessment methods, which have been accordingly mapped to the LO's, are then selected corresponding to the appropriate level of expected learning. Learners at the higher levels are expected to demonstrate deeper analysis, synthesis and evaluation skills and the assessments used should command this. A sample of higher LO's and how they can be realised through learner interaction with the hydraulic system described within this work are outlined by LO (x) & (y) in Table 2.

Table 2. Snapshot of suggested learning outcomes for implementation of systems-approach pedagogy for Level 6 & 7 learners complete with suggested methods of outcome assessment

	Learning Outcomes	**Inherent Scientific Principle**	**Pedagogy**	**Measurement of Outcomes**
(x)	Contrast the energy consumption of a variable speed 'A' rated pumps Vs 'C/D' rated fixed speed pumps.	Affinity Laws	Same as that at Table 2 LO(b) with documentation included which draws on self-direction from the learner	Assessment of Laboratory submission and write up, review of LO's listed in handbook. Observation by trainer, review of stumbling blocks encountered by learners. End of term written assessment
(y)	Relate the operation of the expansion vessel to the pressure/volume relationship of the heating medium.	Boyle's Law	Instruction technologies involved, general principles with self-directed learning to specifics of component/ system performance	Observations made by lecturer during demonstration and subsequent discussion. Assessment of laboratory submission and write up, review of LO's listed in handbook. End of term written assessment
(z)	Justify system upgrade measures to the end-user in a professional and businesslike manner	Technical Communication	Observation of video material, engagement with role-play scripts	Oral assessment by lecturer

As previously mentioned, the pedagogies employed in education, and the resultant processes employed by the students in learning, should be derived from the practice of the discipline [1]. To this end, all learning processes designed by the EU-OPTIMUS initiative were designed in the context of 'complete action' from (i) First contact with the customers, assessment of the problem/job, (ii) Conditional analysis – audit of system, analysis of the knowledge relevant to the problem, calculations, evaluation and planning, (iii) Advising the end-user and securing contract order, (iv) Project realisation and execution of the order, & (v) Quality Control - test records, assuring the results, information transfer to system files and delivery of operation and maintenance files to the end-user. With respect to point no (iii) and LO (z) (see Table 2) the initiative placed considerable emphasis on improving the TC and business skills (soft skills) of the learner. The initiative created sample business contracts and templates, and developed novel instructional modes in the form of video material; complete with role play scripts, between the end-user and craftsman which allow the learner to practice and receive feedback relating to their TC skills. In this manner, the learner is supported in developing effective, professional and businesslike TC skills. The novel instructional modes developed by EU-OPTIMUS for engendering soft skills are pertinent to the wider engineering and product design educational community.

4 CONCLUSION

The novel vehicles for learning (both hard and soft) developed within the EU-OPTIMUS project, the methodologies employed in teaching, and the consequent processes employed by the students in learning, are derived from the practice of the technological discipline. The pedagogies developed are not only transferrable to undergraduate vocational education but are equally applicable to EQF level 6 and 7 engineering and product design programmes.

Traditional laboratory offerings are conducted on a single piece of apparatus or basic subsystem rather than on a system. A realistic model of a system, such as that developed by EU-OPTIMUS assists the lecturer/ lift the meta-ability of the learner from component to system level. Interaction with such a systems based interface helps the student understand the interoperability and technical communication of the components comprising that system, along with the underlying scientific principles underpinning the system design. 3rd level engineering and product design programmes should incorporate system rigs of this type into their normal laboratory offerings to compliment more traditional pedagogies. Witnessing design principles in action aids the learner in increasing their systematic knowledge base and aids the lecturer in the dissemination of complex scientific principles, in the context of the system, to that learner.

An ability to communicate in an effective, professional and businesslike manner is important for the technology graduate. 3rd level programmes involved with the delivery of technical education should look to incorporating opportunities for students to practice and receive feedback relating to their Technical Communication (TC) skills. The novel instructional modes developed by the EU-OPTIMUS initiative, to improve the soft skills of the EQF level 5 learner, in the form of video material, role play scripts and sample business contracts could also be coordinated within engineering and product design curricula.

The development of any such hardware/software instructional modes for higher level learning should commence with the Learning Outcomes (LO's), proceed through the pedagogies and finish with the design/manufacture of the appropriate platform.

REFERENCES

[1] Williams JP. Design: The Only Methodology of Technology? *Journal of Technology Education.* 2000;11(2).

[2] Hennessy S, McCormick R, eds. *The general problem-solving process in technology education: Myth or reality.* London: Routledge; 1994. Banks F, ed; No. Teaching Technology.

[3] Layton. Science Education and Praxis: the Relationship of School Science to Practical Action. *Studies in Science Education.* 1991;19(1):43-79.

[4] Hill AM. Problem Solving in Real-Life Contexts: An Alternative for Design in Technology Education *International Journal of Technology and Design Education.* 1998;8:203-220.

[5] Mioduser D, Dagan O. The effect of alternative approaches to design instruction (structural or functional) on students' mental models of technological design processes. *International Journal of Technology & Design Education.* 2007;17(2):135-148.

[6] Sageev P, Romanowski CJ. A Message from Recent Engineering Graduates in the Workplace: Results of a Survey on Technical Communication Skills. *Journal of Engineering Education.* 2001;90(4):685-693.

[7] Jagnow D-IK, Wolff PD-ID. Kurzbericht - Umweltkommunikation in der mittelständischen wirtschaft am beispiel der optimierung von heizungssystemen durch information und qualifikation zur nachhaltigen nutzung von energieeinsparpotenzialen. *OPTIMUS.* 2006(DBU-AZ 18315). http://www.optimus-online.de/pdf/Kurzbericht-Technik.pdf.

[8] Huber A, Mayer I, Beillan V, Goater A, Trotignon R, Battaglini DE. Refurbishing residential building: A socio-economic analysis of retrofitting projects in five European Countries. 2011. http://www.fedarene.org/documents/projects/EEW2/WSED2011/Huber.pdf. Accessed Oct 2012.

[9] EU-OPTIMUS. EU-OPTIMUS, Saving Resources. 2010; http://eu-optimus.eu/. Accessed Feb 2013, 2013.

[10] de Vos R. EU energy efficiency plans – efficient enough? *Renewable Energy Focus.* 1// 2010;11(1):44-46.

[11] University C. Blooms taxonomy of learning objectives. 2013; http://www.clemson.edu/assessment/assessmentpractices/referencematerials/documents/Blooms%20Taxonomy%20Action%20Verbs.pdf. Accessed March, 2013.