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Encouraging student learning of control by embedding freedom into the curriculum: student perspectives and products

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Abstract: Many engineering students have little inherent interest in control topics and struggle to relate these to their career goals. This paper looks at a novel mechanism for encouraging students to take more ownership of their learning of control topics and, by doing so, improve engagement and learning. Consequently it also fits well into research led teaching philosophies. The main focus here is on the student products for an assignment the author designed in the curriculum which challenged students to develop a learning resource. The paper includes description of one of these student generated resources, which could be shared with or used by the community, and the personal experiences and reflections of the students who produced this resource.

Keywords: Feedback, feedback in bioengineering, student engagement, student responsibility, student satisfaction, student led learning.

1. INTRODUCTION

One of the major challenges of staff responsible for teaching control topics is creating student interest (Murray et al., 2004).

In the author's experience many engineering students perceive themselves as here to learn a particular flavour of engineering and struggle to get motivated for topics they perceive to be peripheral; both control systems and mathematics are obvious examples of this. While departmental staff will be aware that these topics are a core background for an effective accreditated degree (Freeston, 2012), many students are not particularly receptive to being told this. Indeed one could reflect on the well known mantra about good teaching practice (Brown, 2014; Duffy et al., 2012): if you tell a student something they forget (or maybe were not listening in the first place!) whereas if you involve a student in knowledge creation, they remember and understand.

1.1 Problem based learning and independent learning

The above observation underpins much of the reported success on problem based learning (PBL) approaches (Benjamin and Keenan, 2006; Cabeza et al., 2012; Douglas et al., 2012). By giving students authentic problems to work on, they are more likely to be motivated to learn the required theory to tackle the underlying problems. Moreover, one core aim for academic staff is to embed a real enthusiasm for learning in their students and allowing students to find a direct relevance to real problems is one way of achieving this. Of course this has the secondary benefit of increasing the likelihood of students spending significant time studying the relevant topics and time on task is of course one major factor which supports learning.

Nevertheless, this paper is not on project based learning as that tends to define relatively prescriptive problems which can also narrow the potential for student learning of important technical topics. Rather, here the objective is give students a much more open-ended remit with the hope that they will therefore find topics which are of maximum interest to themselves and thus, as a consequence, be even more motivated to spend time on them.

Within the authors' university independent learning is a core learning outcome (Schaefer et al., 2012) and therefore is implicitly part of all technical modules alongside more prescriptive learning outcomes such as definitions for eigenvalues, Nyquist diagrams and the like. This means that staff have some freedom to de-emphasise technical learning outcomes where this is counterbalanced by student growth in other areas linked to professional skills. Of particular note is that the ability to be a competent independent learner will be far more valuable in most careers than knowledge of specific technical content (most engineers will never use a Nyquist diagram in anger again). A key point is that a student who is a confident independent learner, will be confident to pick up any specific technical or mathematical skill required, as and when they need it.

1.2 Embedding formative feedback

One key challenge at University which receives widespread press attention in the UK is the issue of feedback for learning (Feedback Toolkit, 2012). Many students perceive that the feedback they receive is poor in quantity and quality, but in the main, this perception arises due to a poor understanding of and use of the available feedback mechanisms (Schaefer et al., 2012; HEA, 2012). For example (Winstone and Nash, 2015), a key quote is: *The very best feedback is sure to be futile if students do not use it, assimilate it, and implement it in their future goals.*

Instead, one alternative is to help students create and identify their own feedback (Brown, 2014; Sivasubramaniam, 2014), that is, give students control of the feedback process. One popular mechanism for this in the control community is web-based and virtual laboratories (Khan and Vlacic, 2006; Guzman et al., 2006) as these enable students to learn by trial and error, getting immediate feedback on their efforts. However, this paper focuses on another obvious mechanism which is group work and peer assessment (Hughes, 2007; McConlogue et al., 2010; Rossiter, 2013b). When students work in groups towards a shared goal, they have a vested interest in each group member producing high quality work. Consequently, group members are both empowered and motivated to feedback regularly to each other on the quality of the proposed submission.

1.3 Using creative media and professional skills

The rapid development in technology has repercussions on University education in that it provides opportunities to develop learning resources and activities which were not previously possible (Rossiter et al., 2011) and indeed IFAC recognised this in the recently sponsored Internet based control education event (http://ibce15.unibs.it/). Nevertheless, while there has been a lot of focus on how staff might use technology, there has been relatively little discussion of students as creators of knowledge and learning materials (Cruz, 2015; Rossiter, 2015; Gamache, 2002) although this is certainly a growing theme in the educational community.

Some key conclusions are that:

- Students are receptive (Saunders and Hutt, 2012) to more use of modern technology within their assignments and indeed many are enthused by this.
- Encouraging students to develop teaching materials is the final part of the learning cycle which gives the most effective learning experience.

Another growing theme in UK universities (Freeston, 2012) is the need to develop students' professional and/or transferable skills in addition to their technical knowledge. Assignments are a convenient tool whereby students can demonstrate skills such as writing, presentation, communication and so forth. However, increasingly, the workplace is putting more emphasis on effective use of technology for communication so that a presentation is not simply a powerpoint, but also includes demonstrations, videos, posters, webpages and more. For example, a common assignment is to ask students to deliver an assignment as a video (Cruz, 2015; Mclean and McCartan, 2013; Wilson-Medhurst et al., 2012).

Consequently, it is important to give students opportunities to develop these multi-media skills.

1.4 Summary

The first contribution of this paper discusses a project (Rossiter, 2015) with 2nd year bioengineers which seeks to combine the insights discussed in this introduction. The aim is design an assignment which combines a number of attributes:

(1) Gives students freedom to select their own learning objectives (within the general remit of the associated module).
(2) Gives students freedom in how they demonstrate their learning.
(3) Embeds opportunities for frequent and high quality feedback on progress.
(4) Facilitates student enthusiasm and motivation for learning control engineering topics.

A second and more substantial contribution is to focus on the product produced by one group of students and their individual reflections on the efficacy of the process. Section 2 gives some brief background on the assignment brief and organisation. Section 3 looks in detail at the product produced by one group of students. Section 4 gives student reflections and the paper finishes with some conclusions.

2. ASSIGNMENT BRIEF, ORGANISATION AND HISTORICAL DEVELOPMENT

The first author is responsible for teaching control to bioengineers, alongside aerospace engineers and systems engineers in semester 1 of year 2. The bioengineers have a number of parallel modules such as tissue engineering and physiology so that for many of them, classical engineering topics are not inherently interesting and may appear less relevant. Consequently, the first author decided to develop a bespoke assignment for this cohort which embedded the development of research and communication skills alongside learning about the importance of control within bioengineering.

The assignment notionally involves 40 hours of work per student. There are about 70 students in the bioengineering cohort and no teaching support which means the academic has to undertake all the assessment and support alone (as well as alternative assessments for other students on the module). This workload issue is a minor factor in favouring a group as opposed to an individual assignment although in fact, the extra learning and engagement from students though doing a group assignment is by far the most important factor.

In the first instance (2013-14) the first author decided to follow a relatively safe path and asked students to develop a website, in groups, which communicated to fellow students and older school pupils the importance of feedback/control within bioengineering. Students had total freedom in what evidence they used but it was emphasised that marks were awarded for both breadth

and depth, and thus a large number of superficial illustrations could not score a high mark; there needed to be some supporting mathematical analysis of the applications presented. The use of groups was important to enable the peer teaching/learning/feedback benefits.

In the second year he relaxed the brief slightly so that students could present their results in a manner of their own choosing. Although most groups decided to do a website nonetheless, some groups branched out and tried videos and hardware developments.

Illustrations of this early work and student reflections are in Rossiter (2015). It is clear that the overwhelming student perception was that the assignment was positive, as evidenced by a typical student quotes e.g.

(1) *Before the commencement of this project, I had two convictions: (i) system control and feedback was more related to other engineering disciplines such as aerospace and control system engineering and (ii) that it was simply a tool that can be used by bioengineers to solve problems encountered in biomedical instrumentation. This project not only dispelled this myth, it totally changed the way I now view control systems and the concept of feedback. It made me understand that the body is in fact a complex network of feedback control loops working together to produce a single outcome. And that most devices such as bionic eyes and limbs are only an attempt to fix the body's broken feedback loop.*
(2) *My experience can be summed up by Benjamin Franklin's quote: 'Tell me I forget, teach me and I remember. Involve me and I learn'.*
(3) *Whilst completing this project, I learnt and also developed a number of new skills including; in-depth technical examples of feedback in Bioengineering, how to use Prezi software to make a video resource and finally working within a team over a long period of time.*

Students discovered and researched a number of topics which seemed to inspire their interest in feedback: (i) Control Within Brain Computer Interfaces; (ii) Drug Delivery Systems; (iii) Feedback in Pacemakers and (iv) Industrial Control - Bioprocessing. (v) Blood Glucose Regulation; (vi) Pacemakers and (vii) many more.

3. EVIDENCE OF STUDENT WORK AND GAMES IN EDUCATION

In 2015-16, the first author encouraged the students to diversify their assignments even more and invited input from the enterprise section at the University to seed students thinking outside the box. This section reports on the product of one particular group which the authors think will be of interest to the global IFAC community.

3.1 Games and education

It is known that repetition aids learning of core facts and concepts and competition (Rossiter, 2007) encourages time on task. It is also known that interesting games achieve both of these objectives in that participants are keen to do well and may do a game repeatedly to do better still (Hill et al., 2006; Thomas, 2006). Games also encourage discussion and communication between participants and team members which enables peer learning and reinforcement of core understanding following debate, and seeing the correct answer! The challenge of course is to design a game which is both fun to play and embeds effective learning.

3.2 Summary of student product and game principles

Given the efficacy of games as a learning tool, one student group decided to develop their education resource around a game.

They used a relatively classical board game design where players move around the board using dice; this adds some level of chance which thus can contribute a bit of tension and excitement. They also deployed another classical game ploy where the player's skill becomes important. When players reach particular points on the board, they need to answer questions correctly in order to progress. Finally, the overall objective was to successfully visit a number of points around the board, collecting items (learning) as you go. Thus, in order to win a player needs a combination of luck (good dice throws), skill (accurate answering of questions) as well as an effective strategy, which is linked to decisions on how they move around the board.

3.3 Board design

The board was designed around common feedback processes within the human body and thus the basic board had a picture of a human body (figure 1) with images of key organs at the relevant places. A series of tiles mark the paths players can take around the board to enable them to move from one organ to another. The organs and processes selected were:

(1) Pancreas and blood glucose levels.
(2) Heart and a pacemaker.
(3) Antidiuretic hormone and the pituitary gland.
(4) Blood clotting.
(5) Contractions in labour.
(6) Stomach function and digestion.
(7) Hypothalamus, and body temperature.
(8) Bionic eye, bionic leg and bionic hand.

3.4 Question design

The questions are designed to test whether players have engaged with the feedback loops implicit in each organ and process on the playing board. This includes knowledge of technical terms and language as well as an understanding of how the feedback loop works. Some examples are:

(1) What is ADH also commonly known as?
(2) What part of the kidney does ADH directly affect the structure of?
(3) What condition is the excessive production of dilute urea also known as?
(4) What gland secretes ADH?
(5) Which part of the eye do electrical impulses replace?
(6) In the contraction example what stops the positive feedback loop continuing forever?

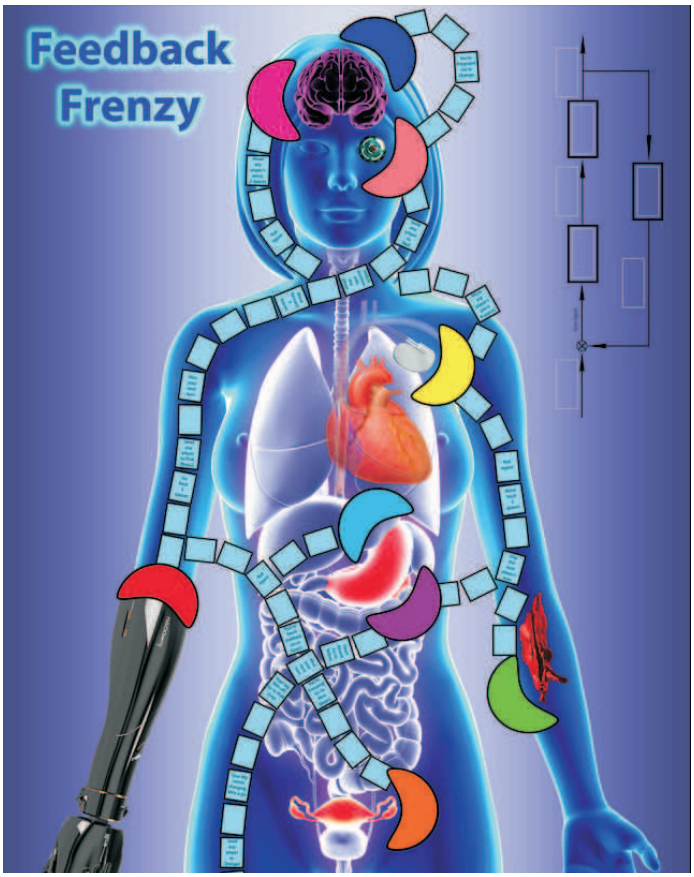

Fig. 1. Design of game board.

(7) What would happen if the progression of birth did not cause more oxytocin release?

Students receive a question at random, but relevant to the particular point on the board where they are located.

3.5 Game manual and instructions

Players are given a manual or book to read in advance of the game. This contains information on the key organs and biological processes that appear in the game. The questions encountered in the game can be answered by reference to the manual, although of course, during play itself, players would not be allowed to use this. One example of typical information in the manual is given next. Similar explanations are derived for all the processes.

Antidiuretic hormone (also known as Vasopressin) is a hormone secreted by the pituitary gland. The primary role of ADH is to regulate the water resorption in the collecting duct of the kidney. ADH causes channels to form in the walls of the collecting duct, causing water to move back into the circulatory system rather than be excreted. Influencing the release of ADH can be very useful in treating certain conditions and symptoms, such as polyuria (excessive production of dilute urea) and hyperuricemia (excess of uric acid in the blood). A device to monitor the levels of this would require a negative feedback system (see figure 2), causing a restoration of homeostasis within the circulatory system.

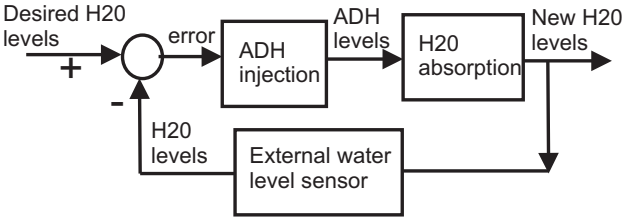

Fig. 2. Feedback illustration for water levels and kidney function.

Remark 1. One could comment that an idealised variant of the game would include much more detail and explanation than in the paragraph above, but one should remember that this assignment was time and credit limited and thus it is not reasonable to expect students to complete a commercial product.

Remark 2. The passing reference to a feedback loop indicates that the target audience is expected to have a passing knowledge of what a feedback loop is. Obviously, some variation in instructions and questions would be needed for a different audience.

4. STUDENT REFLECTIONS AND PERSPECTIVES

In this section an attempt is made to classify some of the reflections into different categories in order to emphasis the multi-faceted nature of the learning that took place.

4.1 Engagement with feedback

A core learning outcome is that students see the relevance of feedback, modelling and control to bioengineering, and of course learn something about these! The following quotes give good evidence that this has taken place.

- *The pacemaker was interesting to research, and I did not find it that difficult to explain how modelling and control are used for the device. For the blood clotting however, I took a different approach and looked at how the biological process itself can be modelled and therefore altered with medicines to give a desired response.*
- *The Control in Bioengineering assignment has given me the opportunity to develop an understanding of how Control Systems Engineering plays an important role in bioengineering and is relevant to our discipline. First and foremost it gave me the opportunity to develop my skills in control in an area which is interesting to me; I have always struggled with understanding block diagrams and choosing these as the basis for our game has meant that I have been able to improve in this area. I also have enjoyed learning much more about feedback systems within the body and in medical devices.*
- *It was fascinating to see how these systems can be used to improve a persons everyday life and see real-life applications of theory we have learnt.*
- *After some thought I decided to use a feedback system in a prosthetic leg socket that used balloons to relay information about weight on the leg to the user and*

thus incorporate them in the overall feedback loop to achieve a correct gait. This was very interesting and developed my understanding of how bioengineering can use combinations of electrical and biological feedback systems to create an overall feedback loop.

4.2 Personal development, negotiation and reflection

One main learning outcome of any degree is for students to recognise and actively reflect upon their own development and how this helps them in their long term aspirations. Some evidence of this taking place is given in the following quotes.

- *Overall the project was a valuable way to further our knowledge of our own discipline and to develop our skills in control engineering. It was enjoyable and we are proud of the resource we have produced and are even considering the possibility of using it to promote bioengineering on open days and in schools.*
- *I am very proud of the resource we managed to produce, as it is both relatively simple but packed with detailed technical information.*
- *Initially it was quite difficult to fully understand how modelling could be used in biological processes, however after much research I feel that I now better understand the benefits and advantages that modelling can bring to controlling biological processes in a particular way, and feel that I appreciate the applications of control and modelling on feedback a lot more than I did before the project.*
- *Doing this gave me the chance to learn about a lot of bioengineering that I hadn't considered control to be a part of, more specifically modelling biological systems such as contractions.*
- *We used many other board games as inspiration, such as Monopoly. We had to find a way for one player to win, whilst being asked questions in order to test their knowledge of the field. We settled on the idea of completing a block diagram (one of the simpler topics in ACS) being the primary objective.*

4.3 Team working and professional skills

As a group assignment, it was essential that groups worked effectively together, had clear goals, effective negotiation strategies, regular meetings and so forth. Also, presentation aspects required the students to engage with multimedia and ask questions about how an audience would relate to their product. Some evidence that this assignment facilitated the development of these core skills is given by the following quotes:

- *On the whole, I believe the project to have been successful, and have a greater appreciation for the dynamics of a team.*
- *Creating the board proved to be a complicated task; as we had agreed on A1 size, I had to ensure the image was of a high enough quality to look sharp and unblurred even when blown up to this larger size, whilst still including everything we wanted on the board. It required me to look through numerous images until I found appropriate images of sufficient quality. I then had to install, and learn how to use, Adobe Photoshop to construct the board, editing various images together smoothly to ensure all elements we wanted to include were present, along with working out the layout for the path the game players would follow etc. and fine-tuning the mechanics of the game.*
- *The first few group meetings were oriented towards actually deciding how our board game would function, making it competitive and fun but still being an informative and educational resource. We decided to incorporate feedback loops and use various stations located around the body so that we could offer information on numerous parts of the body to convey the breadth of functions feedback offers across all aspects of bioengineering.*
- *With this in mind, we set about developing the mechanics of the board game. This proved to be the most complex part of the project, with myself and Nick taking the lead due to our interest in making it a playable game rather than just a selection of facts and board with some dice.*
- *As a bioengineer I already was interested in this area however was pleased at the opportunity to produce a resource that would give other people the chance to see what bioengineering and control is about. This is why I joined a group who wanted to create a board game; we wanted something that was accessible whilst still informative, and most importantly engaging and fun but still met the criteria of a resource.*

5. CONCLUSION

The paper has given an overview of the potential benefits of giving students open-ended assignments and encouraging students to use multi-media formats to teach their findings to others. Specifically, it has demonstrated the benefits of the proposed teaching approach in engaging students in the importance and potential benefits of control engineering. It is clear that the majority of students get enthused by the freedom to choose both the media and subject matter of their choice (within the remit of a given module) and this seems to enable deep engagement with the research topics selected. Moreover, the emphasis on the assignment of producing resources for teaching others helps achieve the highest aspect of Blooms taxonomy; to teach something requires deep understanding.

The main contribution of this paper is to highlight the resource produced by one student group in 2015-16. Drawing on the literature which emphasises the efficacy of games for supporting learning, the students developed a game for players to learn about the presence, workings and importance of feedback within the human body. Success at the game requires players to gain good insight into a number of physiological feedback processes. However, more significantly, the authors of the game gained a deep understanding for themselves alongside developing a number of professional skills.

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