Preprints of the 19th World Congress
The International Federation of Automatic Control
Cape Town, South Africa. August 24-29, 2014

Lecture flipping for control engineers

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Abstract: Lecture flipping is a relatively new concept (Mazur, 2012) in higher education. This paper serves as a test case of lecture flipping used in the context of some classical control courses. Specifically the paper discusses the resource implications, and availability including how resources can be accessed by the wider community. Also, the paper includes gives detailed staff reflections on the efficacy of the approach and some preliminary student evaluation.

Keywords: Independent learning, lecture videos, lecture flipping.

1. INTRODUCTION

Common perceptions on what constitutes an effective education and delivery of university curricula are changing rapidly. This is in part due to the ever increasing power of technology and with it solutions that were not previously available (JISC , 2013) but also in response to an increased interest across the globe in the value of good pedagogy (see Higher Education Academy, ALT-C conference series, and so on). A clear example of this in the UK is the requirement that all new academic staff participate in, and pass, an accredited programme on learning and teaching to masters level. Historically the requirement would have been participation alone and on a much less intensive or rigorous programme. Naturally IFAC has long since recognised the key role of education through its EDCOM committee and recent initiatives to ensure that EDCOM has representation on all other technical committees.

One challenge that faces IFAC is the desire to capture and disseminate best practice in control education. Clearly the ADVANCES in CONTROL EDUCATION SYMPOSIUM series is one such mechanism, but there is also the desire for more of a one-stop-shop website hosted and managed by the IFAC community to capture and share ideas and resources which are effective for control education. Some early seeds to this were produced for the IFAC celebration (IFAC resources , 2013) but there has been slow progress on how to manage such a website in the long term. Notwithstanding this ongoing project however, there is a clear need for sharing of effective control education resources across a range of issues such as:

(1) What constitutes an effective curriculum for a 1st course in control? (Rossiter et al, 2008; Astrom , 2006; Boyd , 2012) How is this different depending upon the cohort (Murray, 2013)?
(2) What is the role of remote and virtual laboratories and what is good practice in the design and delivery of these? (Khan et al, 2006; Guzman et al, 2008),...
(3) What quality but cost effective laboratories are available for departments to purchase? (Taylor et al , 2013)
(4) What is the best way to deliver lectures (Mazur, 2012; Abdulwahed, 2010; Rossiter , 2013)?

This paper will focus its attention to the last point which is the lecture delivery itself. Specifically the aim is to revisit the role of the still popular didactic lecture and ask how we as a community could or should update this model for the 21st century. Also, what support is needed for staff to do this? The paper builds on a pilot study from (Rossiter , 2013) and looks at a large scale delivery to 1st and 2nd year class sizes of over 200.

The next section will give some background on pedagogy and ideas that are currently topical in the literature. This is followed by a more detailed discussion on resources implications for lecture flipping and a showcase of the resources that have been developed at Sheffield. Section 4 then gives an evaluation with the focus being on staff as it is the staff who are the main implementers. The paper then finishes with conclusions.

2. BACKGROUND

There is a well recognised acceptance that student learning is best supported by students being active in the process; activities which encourage student passivity are, on the whole, much less effective. It is perhaps not surprising then that huge amounts of work have gone into designing learning processes which encourage student activity.

Along the same lines, it is recognised that resources are more engaging and memorable if they engage more senses and thus which include audio, video, movement and not just text on a page. Obvious examples are the recent emphasis on laboratories which are accessible via the internet. Many of these are virtual laboratories (Khan et al, 2006; Guzman et al, 2008; Cameron, 2009) which students can access anytime and almost anywhere. The animation and interactivity in these laboratories enable students to *try things out* and experiment and thus learn by doing. Moreover, they remove the need for complex and time consuming algebra before one can see the consequence of a modification and thus support rapid trial and error type learning of core concepts.

The availability of virtual (or remote laboratories) is one example of resources which also support another growing

need, that is the recognition that University education is much less about the facts and algorithms you learn and more about learning to learn (Thomas, 2012); this is a common mantra repeated by industrialists, they want graduates who are adaptable, independent and learn quickly. Readers will notice however that this observation is at odds with the conventional delivery model of lectures, tutorials and exams whereby students are largely passive in lectures which *deliver* the material and can get good marks by reproducing the lecture material, often with only minor modifications, in an exam. Unless the induction processes and curriculum are well designed (Yorke, 2006), (Rossiter et al, 2012) students will rapidly accept this culture as the norm and thus not be sufficiently challenged to develop their independent learning skills.

Within the author's department a project on independent learning of MATLAB trialled the use of pre-recorded lectures of core MATLAB topics (Rossiter et al, 2010) with only occasional question and answer lectures. The idea was that students accessed the pre-recorded lectures at their own convenience and took control of their own learning. They can run these in parallel to MATLAB and thus pause the videos to try things out. The videos contain frequent references to m-files and concepts and encourages students to open these and run them, or edit them or create their own files to show they can do it. Regular tutorial sessions provide students with the opportunity to ask questions and occasional lectures are delivered more as question and answer sessions and to highlight the key skills/assessments the department requires. An extended evaluation (Rossiter et al, 2010) has shown that despite some of the videos being somewhat dated by now, the students have continued to be very positive about this approach to learning and far happier than when a more conventional lecture model was used.

In parallel with these developments, the community at large had being following a similar direction. It was recognised that the pervasiveness of the web and with now relatively cheap mechanisms for creating video, it is possible to reinvent the traditional lecturing model (Mathtutor, 2012), (Mazur, 2012) (Williams and Fardon, 2005), (Saunders and Hutt, 2012). In simple terms the argument is as follows (with variations as appropriate to the context):

(1) Students directed to learning resources they must go through in advance of a lecture.
(2) The lecture asks students to apply the learning they have done to problem solving.
(3) The lecture facilitates group discussion and peer learning so that students help each other diagnose common misunderstandings, good solutions and together make progress.
(4) Staff act as a moderator to correct errors, draw things together, and if necessary, give some brief didactic presentations on core learning that is shown to be needed from observing the students.

There are several examples of this process already (Weblinks , 2013) although typically the focus seems to be on small cohorts as use is made of modern class rooms which contain tables for groups to sit around and discuss. Most Universities have a limited number of such rooms and moreover, these are not suitable for very large cohorts; the author has classes of 250 and some colleagues' classes are larger. Consequently it would be interesting and valuable to explore how well this concept can be extended to very large classes, but also to determine what 'resources' are required for such a lecture flipping process to be implemented successfully and these questions are covered next.

The author uses a simple model of clicker (students respond via a smart device such as a phone or clicker and displays a summary of responses) based questions in the lecture as a format for testing and engaging students. He encourages students to work in small groups and convince each other of what the answer should be, thus supporting some peer learning and more activity - noise is fine and hopefully students get more emotionally engaged by having a group discussion. Questions are re-polled where there is widespread confusion, some times with a hint from the front, and sometimes not; students will remember better what they work out for themselves but the lecturer will give 5 minute reviews of topics where this is clearly needed.

3. RESOURCE IMPLICATIONS FOR LECTURE FLIPPING

It is well known that 1st year students are relatively fragile (Yorke, 2006; Thomas, 2012) and induction needs to be handled carefully. While on the one hand students expect a change from school, on the other hand they still have a relatively fixed idea of what education is and certainly in the UK and many other countries this has been the ability to pass exams rather than to learn *per se*. Given they already have 13 years of education experience, they will not change overnight to accept a new interpretation of what education is about. Transition to a view whereby education is about the ability to learn, rather than the skill to pass a specific exam and also the ability to be a critical learner and a problem solver will likely be slow and take more than the brief time at University.

Consequently while students need to be challenged and exposed to new ideas and learning styles immediately, it is also important that they feel safe in this new environment, especially where they may for the first time be living far away from home and thus have many other stresses. If students do not feel they have sufficient clarity and consistency in what is expected of them or confidence in how they can achieve this, any delivery mechanism is likely to fail. The safety barriers can be reduced more in later years, but it would be dangerous to do so too quickly, especially where students are likely to be receiving relatively conventional didactic lectures from many staff which could reinforce their view on what to expect.

3.1 Consistency in resources

The author took the decision that, certainly for year 1 classes, it is safer to use resources which are internally consistent in terms of notation and assumptions and thus to avoid potential confusion. While ultimately students will be exposed to different notations and the possibility that different people make different assumptions, for different reasons, too much variability at the outset is likely to look like chaos. Moreover, the author wanted a guarantee of easy access to any resources that he expected students to

use; such a guarantee is harder to give where a resource is on an external website. Readers may also note that in the UK, and the authors suspects in many countries, it is not possible in general to require students to purchase or guarantee access to a given text book and thus one cannot easily build modules around textbooks as this can be perceived as unfair or divisive; consequently text books are used mostly as secondary rather than primary sources.

For these reasons, rather than pulling together a possibly eclectic mix of resources from various websites, the author decided to form a *one stop shop* site of resources for modules covering topics in introductory modelling, analysis and control. The site meets certain simple requirements:

(1) Free access for students at Sheffield.
(2) Easy access for all students at Sheffield.
(3) Internal consistency in terms of notation, assumptions and style.
(4) A link to Sheffield, so students recognised this and had confidence in the content.
(5) Content must develop in a systematic fashion so that students accessing resources in order could follow the developments easily.
(6) A clear organisation of material should be available so students can plot a route through the resources.

Remark 1. As it happens, the author's University supports open access and thus the materials are freely available on Youtube. A separate website (Rossiter , 2012) has been used to form the organisation views and links to all the videos, powerpoint files and MATLAB files. Moreover, the University is planning to port these to iTunesU which has even greater accessibility.

3.2 Resources for systems and control

The resources are currently organised into 5 chapters although there are plans to extend this. The beauty of a web-based book is that one does not need to fix the final structure as with a printed book, but rather it can evolve and expand much more easily. The current chapters are:

(1) INTRODUCTION TO MODELLING SIMPLE PHYSICAL SYSTEMS
(2) INTRODUCTION TO SYSTEM RESPONSES AND LAPLACE METHODS
(3) INTRODUCTION TO FEEDBACK
(4) CLASSICAL CONTROL ANALYSIS AND DESIGN
(5) MATHEMATICS SKILLS

The author recognises that many core topics are not yet included, but this resource is a start point not an end point. It would be interesting to hear about the topics colleagues felt should be included in such as site - for now aimed mainly at introductory topics. The author has also not put much emphasis on complex tutorial sheets or case studies taking the view that the resources are to cover *the basics*; once students have mastered the basics they should be competent to access the many excellent text books and other resources to broaden and deepen their skills.

Each chapter is made up of a number of sections and each section comprises numerous videos and in some cases MATLAB files. The videos in each section are listed with a fixed naming terminology to make the organisation clear,

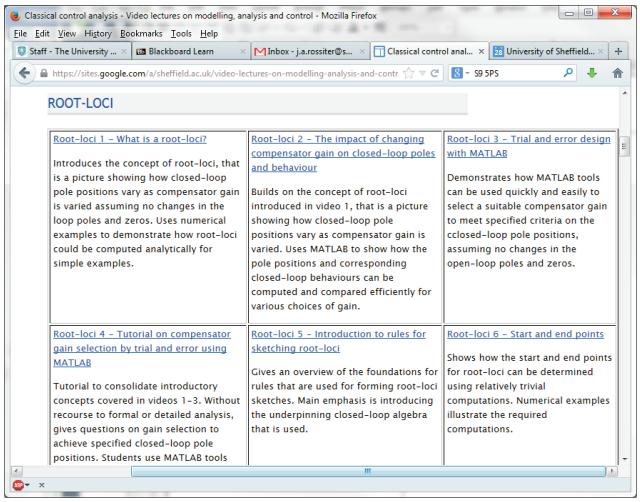

Fig. 1. Screen dump from section of book webpage.

so for example (see figure 1) there are videos: (i) Root-loci 1 - What is a root-loci?; (ii) Root-loci 2 - The impact of changing compensator gain on closed-loop poles and behaviour; (iii) Root-loci 3 - Trial and error design with MATLAB and so on. The first part of the name gives the overall topic and ordering in the list and the second part of the title gives an impression of the main content of the video. Students are advised to view videos in order beginning from 1 as the videos will often refer back to earlier videos in the listing, however this is not compulsory as each video has a 1-2 minute introduction which outlines key assumptions and notation. Thus, a student seeking clarification or revising could go straight to the relevant video and use it without difficulty.

Introduction to modelling simple physical systems This chapter is made up of 4 sections each of which will comprise a number of videos. The intention is to introduce concepts of physical modelling to a level expected of a year 1 engineer, but not beyond. Consequently the different sections cover models with no dynamics, models with 1st order dynamics and models with 2nd order dynamics. The first three sections assume linearity and hence the final section is a very brief introduction to definitions for linearity and non-linearity.

Introduction to system responses and Laplace methods This chapter includes sections which introduce students to the concepts of behaviours and analogies between apparently very different systems. Thus in the first instance there are sections on 1st and 2nd order responses which are straightforward and give useful generic insights. For higher order systems and the longer term the videos introduce Laplace tools, inverse Laplace and links between Laplace transforms and behaviour. At this point the reader may wish to note that although the videos give a number of numerical examples, an underlying message throughout is that paper and pen exercise are to aid understanding and insight, but in the long term it makes sense to use a computer for algebra and number crunching.

Introduction to feedback This chapter introduces the concept of feedback, what is it and why do we need it? The focus is on introductory concepts that can be

handled by year 1 students and indeed some of this is introduced in semester 1 of year 1. Therefore students are introduced to transfer functions and block diagram notation and subsequently to elementary analysis of how pole positions and offset depend on the compensator for 1st and 2nd order systems; some heuristic PI design (Rossiter , 2012) methods are introduced to demystify control design. Finally, MATLAB is used extensively to encourage students to learn by doing.

Classical control analysis and design methods This chapter covers classical content that many industrialists and others feel it is useful for students to understand (Rossiter et al, 2008). Thus there are sections on root-loci, Bode, Nyquist and margins. Throughout this chapter there is a lot of use of MATLAB tools to perform analysis and demonstrate the impact of changes. There is no discussion of state-space methods as generally that is a topic taken in later years rather than years 1 and 2. However, this could be added in due course as time permits.

Mathematical skills There are already a large number of good quality resources for common mathematical topics (Mathtutor, 2012) and hence this brief chapter has the prime role of offering alternative insights or emphasis that could be useful for engineers. Currently the topics are simultaneous equations and complex number algebra but more may be added in due course.

4. EVALUATION

The key purpose of the evaluation was to discern whether the resources produced are considered useful to both the community and students in the author's own institution. The former is more of a generic question in that there is a recognition that good resources can help globally and it is useful to have some insight into this. Moreover it is important to analyse both the efficacy of lecture flipping and whether the resources available are appropriate to support this. However there is also a third important question which links to staff perceptions; ultimately staff take responsibility for delivering teaching and hence their views on what works and its efficiency are useful to share.

4.1 Views of international users

The resources have not been publicised and thus will only be used by external students who carry out an optimistic search on google or youtube and find them. Nevertheless, it is encouraging that quite a large number appear to have found these and even without the benefit of the organisation chart (Rossiter , 2012) have found these useful. Some unsolicited comments that have been posted by international users include:

- *its just great how carefully u thought of making these videos... many teachers just does not ffeel the need to go through the basics.. but u always introduce some fundamentals, basics before explaining any concept... i know u put a lot of thought process before making those videos what the student needs and accordingly u modified ur course materials and teaching process... amazing jobs.. hats of to u ...*
- *Thanks for these videos.*
- *Wish I was your student!*
- *You are doing a great job at explaining and posting videos.*
- *Your lectures are excellent , keep it up!*

4.2 Early evaluation of 3rd year chemical engineers

While the resources were still to some extent incomplete, they were used with a class of 3rd year engineers who do a single course covering both modelling and an introduction to control. An evaluation of this was already disseminated in (Rossiter , 2013) and thus here a brief summary only is given. Perhaps it is unsurprising that the majority think the existence of the videos is a good idea and helpful, but of more interest is the extent to which their existence is enabling students to improve or manage their own learning

Clearly there was a culture shock for the 3rd years where they were not used to 'preparing' for lectures and thus while the majority eventually got into the hang of this, a minority did not like this expectation. The use of lecture flipping techniques for this cohort was appreciated by many, but not by a few who wanted a return to didactic delivery. Overall, the analysis indicates a successful pilot and gave encouragement for a wider scale roll out once the resources were complete enough.

4.3 Staff perceptions

Staff motivation for this project was multi-faceted. Critically there was a recognition that students increasingly did not use traditional text books and were resorting to whatever they could find on the web. Earlier learning and teaching projects had given very strong evidence for the potential of audio and video resources to support students. Moreover repeated cohorts had emphasised their desire to have more video/audio resources to learn or revise from. It is possible just to record lectures and make these available and of course that is well received, but the disadvantage of that is the potentially disjointed nature of the recordings due to an class interaction and absence of any class activities which are not captured by the data projector. Also, this did not tackle the fundamental issue of encouraging more student independence as it left the lecture as the prime didactic delivery mechanism.

By creating simple on line lectures for each topic the author removed the need to ensure multiple key points were covered in lectures as he knew an effective and consistent resource was available on line. Instead, lecture time could be used for real interaction with the students and focussed on issues that were causing the most problems; no time need be wasted on what students found straightforward. There is always a transient issue at the beginning of term with students perhaps unconvinced you really want them to view videos in advance and thus many arriving unprepared. However there are simple things staff can do.

(1) Be consistent and insistent. Students will soon realise that there is no point attending lectures on problem solving, reflection and the like if they have not done the required preparation. They also see the benefits if they have down the preparation because the new format gives them real and valuable feedback. [Of course

there will be some backlash from those students who resent having to work and prepare outside lectures!]

(2) The removal of time pressure to cover everything in a lecture means that staff can be a more relaxed at revisiting topics where there is a large scale confusion over some issue. Students will see and appreciate the flexibility of staff to focus on topics where there is most need, although weaker students can resent the fact that well understood topics are skipped.

The author has found lectures much more enjoyable this year than in the past. There has been a very clear buzz in the classroom when students have worked on problems together and negotiated over what is the correct answer. Staff impression is that students leave the lecture with increased confidence in their own competence and some cases clear awareness over their own weaknesses and thus enough information to study effectively, or seek help. Students have been more willing to be forthright, to ask questions during the lecture and raise concerns. Of course this is too some extent anecdotal but the author is convinced enough to persevere with class sizes over 200!

4.4 Preliminary views from year 1 and 2 cohorts in 2013-14

Only half way through semester is too early to get conclusive student views, but it is felt the reader would appreciate some preliminary evaluation of student views. A few simple questions were asked using clickers during a week 6 lecture and some of the responses from the 2nd year cohort are summarised in figures 2-6 (the caption summarises differences with year 1 responses); the majority of those present responded. There is an obvious but sizeable minority who are struggling with the change in approach to learning although the majority seem to approve (textual comments later in semester reinforce this summary).

Unsurprisingly the vast majority thought the videos were useful (12% disagreed) and a concept to be expanded. A key statistic is that only 30% of both 1st and 2nd year classes wanted a return to didactic lectures, so the change is working well of the majority. The author's institution has a high number of overseas students and future work could seek to unpick a little more whether there is a significant difference in responses linked to cultural/education background. Figure 5 demonstrates that one key aim, which is to encourage students to *do more work and prepare conscientiously*, is still a long way off successful.

There is a noticeable difference between year 1 and year 2 students; the author suspects this is largely because the year 2 students are slightly more mature whereas the year 1 students are still in transition from school and struggling more to take responsibility for their own learning; of course the view in the author's institution is that there is no benefit in delaying transition to different expectations and it is better to insist on what is expected straight away, albeit with proper support. In this case year 1 students get a two hour tutorial every fortnight as extra support.

5. CONCLUSIONS AND FUTURE WORK

This paper gives a case study in resources and delivery for lecture flipping in modelling and control topics. The

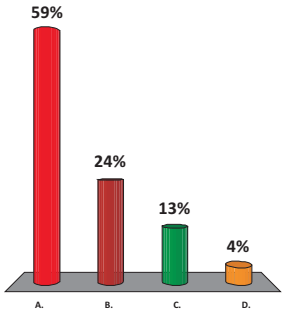

Fig. 2. I have looked at the preparation videos (many times, a few times, once, no). Notably participation by year 1 students was significantly lower!

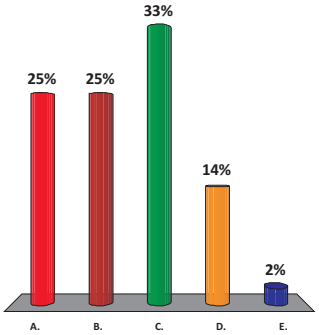

Fig. 3. I have struggled with the discipline of preparing for lecture activities by doing the suitable viewing in advance (strongly agree, agree, neutral, disagree, no comment). Notably 65% of year 1 students struggled with this discipline, so a higher proportion!

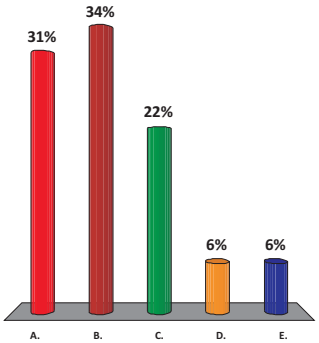

Fig. 4. Are the online videos suitable for preparation activities for lectures? (strongly agree, agree, neutral, disagree, no comment). It is notable that a higher proportion of year 1 students disagreed here.

increasing interest in lecture flipping has formed a justification for a proper trial in the control community. However, for a trial to take place, suitable and effective resources are required. This paper describes such a set of resources which are suitable for use in years 1 and 2 of an engineering degree and gives evidence that their use, in combination with lecture flipping, has been encouraging. The main challenge is the minority who still want purely didactic lectures, but the author sees this more as a reassertion of

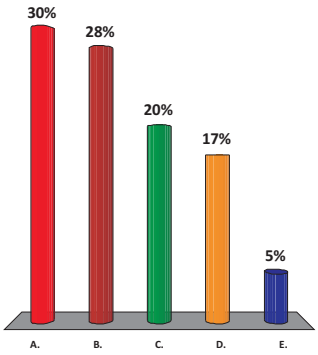

Fig. 5. The requirement to view videos in advance of lectures has enabled or forced me to take more control of my learning and time management (strongly agree, agree, neutral, disagree, no comment). In this case 65% of year 1 students did not agree!

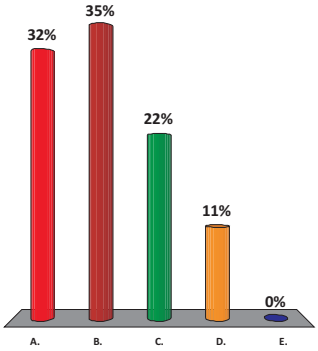

Fig. 6. I like having lecture time focussed on discussion, case studies and problem solving (strongly agree, agree, neutral, disagree, no comment). 20% of year 1 students disagreed which is higher.

the need to help those students appreciate the skills they need to develop to be productive graduate engineers

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