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A First Course in Systems and Control Engineering: IEEE Technical Committee on Control Education

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Introduction

In the recent years, the IEEE technical committee on control education (http://control-education.ieeecss.org/control-home) has focussed on two main tasks: (i) supporting the partner IFAC community in a survey of the world wide community concerning priorities in University engineering control courses [1] and (ii) outreach activities. The latter of these activities is currently undergoing a major refresh under Daniel Abramovitch and hopefully will be reported in a later submission and thus this contribution is focused on the former project. Moreover, we will extend this slightly in the light of the current COVID-19 pandemic to reflect on effective teaching practice.

Background on Survey

Most engineering undergraduates take at least one course on control engineering, but historically there has been significant variety in the focus of these courses, both across different institutions and countries. The technical committee felt that it would help both academics, students, and employers if there was some international consensus on what the priorities should be, while of course accepting there would be some discipline and institutional differences. The survey demonstrated a remarkable consistency of views across the community for what could be considered 60-70% of the content, with differences largely being on what topics would be included in the last few weeks. As the results are already published [1], here we focus on summarising some of the core conclusions and then develop this by looking at some of the repercussions on delivery. More specifically we give focus to developments in the community that support the survey outcomes while also being pertinent to the distance learning scenarios that are increasingly commonplace, and indeed necessary during the COVID-19 pandemic.

Main survey outcomes

There was an overwhelming consensus that a first course should focus on concepts, case studies, motivation, context and so forth as shown by the responses in Figure 1.

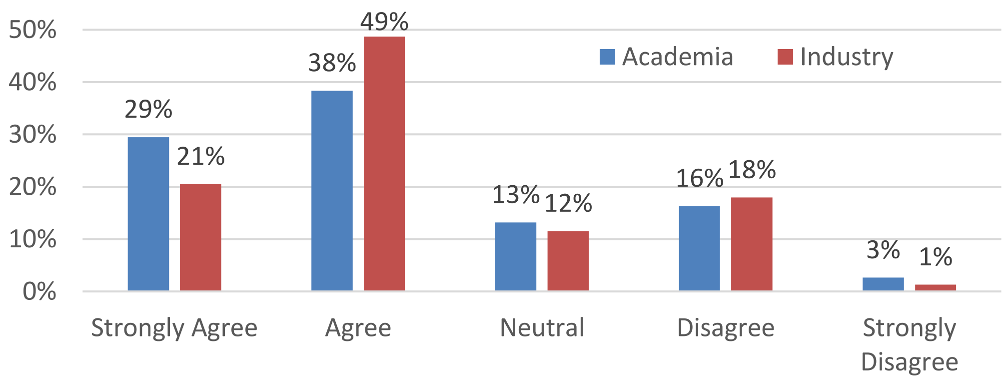

Figure 1. Survey response: focus on concepts, case studies, motivation, and context.

It is more important that students understand why feedback is important and understand its impact, rather than they become fully mathematically literate with a range of analysis and design tools.

While some mathematical depth/rigour is ultimately important, students can develop this in time as they need it, so initially this is included where necessary, but not as an end in itself. Consequently, anything requiring more advanced mathematical tools should be part of a second rather than a first course. The assessment of a first course is that it should not include too much algebra and proofs and instead should focus on understanding of concepts, perhaps supported by software for number crunching and experiments as shown by the responses in Figure 2. Both academic and industrial responses are in agreement on these points for a first course.

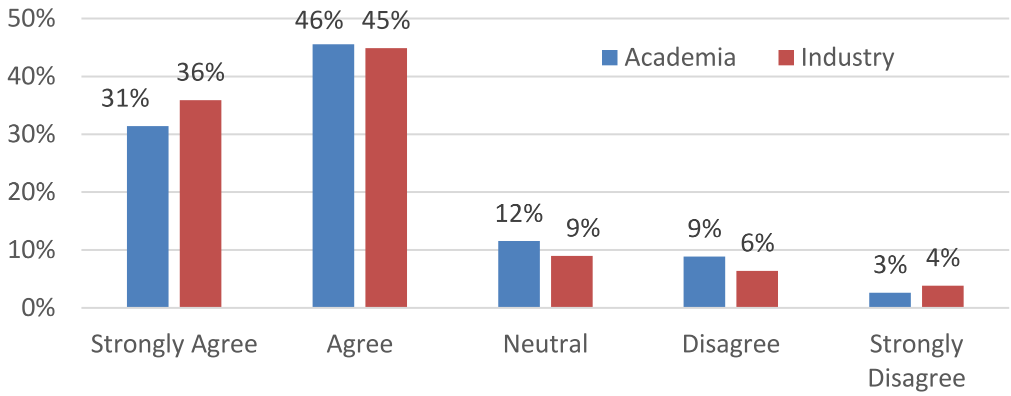

Figure 2. Survey response: first course with simulations and experiments for conceptual understanding

There was also consensus about the importance of first principles modelling, dynamics and quantification of behaviours. However, only some disciplines were keen on including state space approaches with most feeling these models could

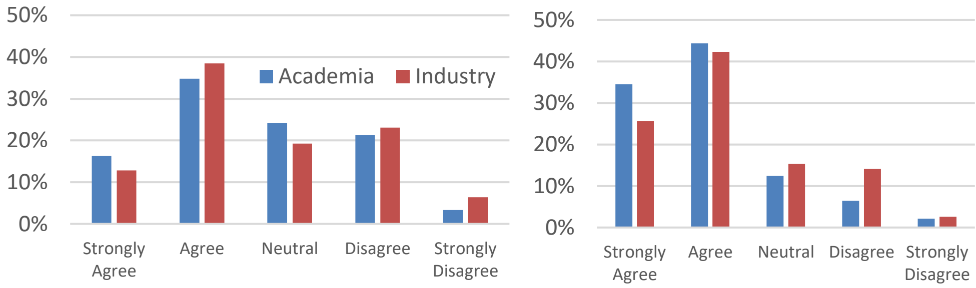

Figure 3. Survey response: State space (left) and Laplace / PID control (right)

come in a later course. Indeed, while not an overwhelming consensus, there was still a majority view that Laplace Transform tools were appropriate to a first course as shown in Figure 3.

It was taken for granted that not only should exposure to hardware be incorporated, but also, as much as possible, a first course should introduce students to authentic issues and challenges that will be encountered on industrial systems. A specific example which split the respondents was whether digital control should be included; this is obviously increasingly relevant but its inclusion potentially comes at the price of excluding something else.

There was a fairly universal desire for some exposure to PID tuning to be in a first course, given these still dominate industrial practice and thus employers would expect some awareness as a minimum. Indeed in terms of importance this topic ranked 3rd and 5th respectively for industrial and academic respondents, thus more important than most topics (e.g. block diagrams, delays, signal processing, etc.)

While there is some evidence of national and discipline differences, that discussion is not pertinent to this paper. However, what is more important is the recognition that, having agreed on a generic curriculum for a first course, the community needs to be better placed to curate and share effective and relevant learning resources and practices with each other.

Teaching Pedagogies

Good practice in education is constantly evolving and so it is useful for academic staff whose prime role is research, to have a concise summary of good practice with which they can engage and implement. The engineering control community tends to be quite pragmatic in its approach and numerous proposals have been published [2] over recent years (such as at the IFAC Advances in Control Education Symposiums and special sessions at major conferences).

The results from the control curriculum survey [1] support the argument for more project-based learning in control education. Traditional control curricula start from rigorous mathematical models and spend several weeks of mathematical manipulations before arriving to simple transfer functions for practical applications. During this time students lose motivation and fail to see the connection to real world practice. Project-based learning flips this progression backwards. It starts with a relatively simple practical control problem, such as temperature control, and students develop control concepts and control intuition in the context of the specific problem, in many cases by trial and error. Students then develop a much greater appreciation for the practical importance and relevance of the mathematical analysis. An essential prerequisite for project-based learning is the access to control laboratories.

One area of particular expertise and interest within the control community is how to support student engagement with laboratory activities, largely hardware based but also software based. The community in Spain has been particularly active in developing and promoting online access to virtual and remote laboratories [3-7] and their work provides resources that are both accessible across the globe, but also give templates for those who may wish to develop an in-house equivalent. Further evidence of pragmatism also appeared in several recent publications such as [8, 9].

In parallel, a number of researchers have pursued the concept of take-home laboratories [10,11], that is real hardware that students can take home and thus access and experiment with 24/7 in comfort, and using their own laptops. It is now accepted that such equipment can be built for as little as 35$USD a unit, cheap enough to purchase and lend out to the entire cohort and thus incorporate interesting open-ended assignments and activities. A very successful and widely adopted kit is the one in [10] (Figure 4) which comes with a large number of prepared files in Python and MATLAB so that students can focus on the application of their learning. Within the first author's department, they have developed a take home static helicopter kit ([11] and Figure 5) which fits in a small toolbox to support more advanced control modules; this does however cost about 300$USD per unit.

Figure 4: Temperature control lab kit [10]

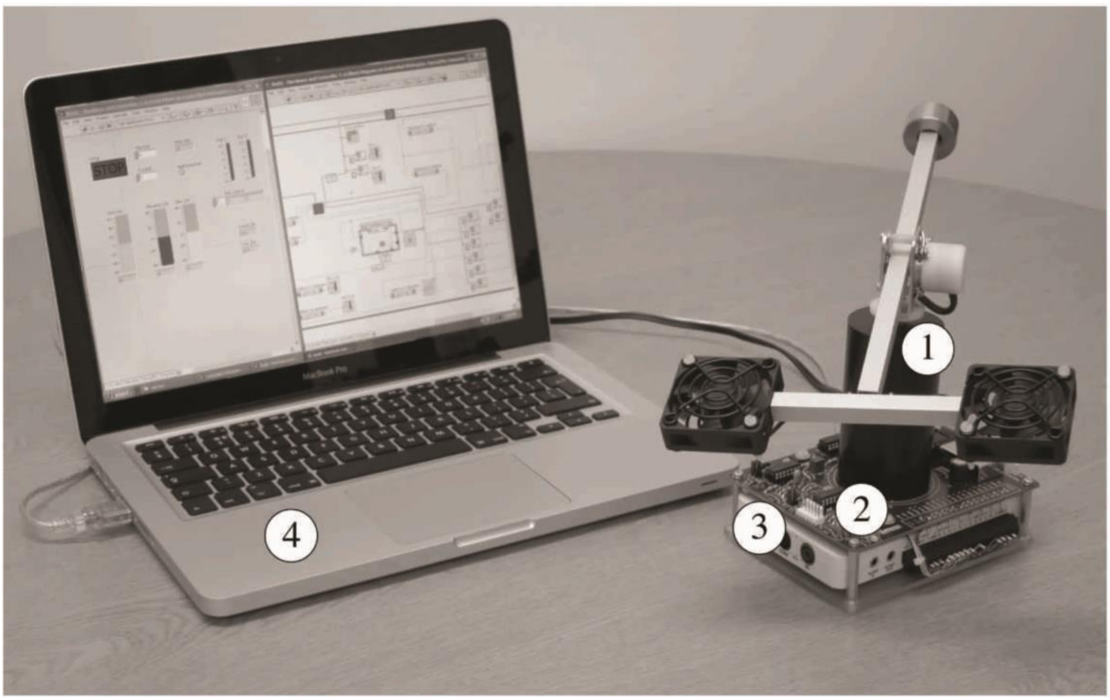

Figure 5: Example of a take home helicopter kit [11] which students can connect to their laptops via a USB

A core skill for graduate engineers is the ability to learn independently [12] and be confident in applying that learning to unseen scenarios, for example through problem solving. A traditional didactic lecture format may not support this as it can encourage students to perceive the content as given/fixed rather than something they have a role in creating and understanding. Hence, the delivery needs to put sufficient onus on students to self-assess their own progress, to reflect and to manage their learning actively. Staff can scaffold this by providing students with guidance and support in how to develop their independent learning and self-assessment skills. Simple examples include computer quizzes and using MATLAB tools to check their work. More advanced pedagogies such as flipped learning [13-15] take this one step further and can be very effective in helping students engage with their progress and develop confidence. A number of tools such as lecture response systems are now widely available to support these types of sessions.

It is interesting that the increasing focus on independent learning within higher institutions was actually accelerated by the recent COVID-19 pandemic which is actively forcing many lecturing staff to update their delivery and resources accordingly. There is pressure to provide many more standalone resources [16, 17] including not just notes but short videos on core topics, quizzes, problems and web accessible laboratory activities. Such advances allow the contact time to focus more on the flipped learning model and active engagement, that is, the more challenging aspects in a course, group discussions and problem solving.

A benchmark control course in the post COVID-19 era

A benchmark control course [18] should aim to contain a number of core components.

(1) Laboratory activities: good quality hardware if possible and in addition virtual and/or remote laboratories and/or take-home kit that can be accessed 24/7 to reinforce and support further and deeper learning. These activities should be embedded into assessment to encourage engagement.

(2) Self-assessment resources such as computer-based quizzes which students can use independently to assess their progress. Again, embedding these into assessment will encourage better student engagement. Projects at the author's institution are looking at the potential role of such quizzes to form a baseline assessment for accreditation purposes [12] thus enabling end of year exams/assignments to focus solely on more challenging and interesting aspects.

(3) Appropriate learning tools provided on modern virtual learning environments (VLE) such as discussions forums, file sharing, quizzes, assignments handling, feedback tools and more.

(4) Learning outcomes for accreditation [12] which go beyond simple technical learning such as presentation skills, problem solving, independent learning and so forth.

Hence a simple example of an introductory course covering modelling, behaviour and an introduction to feedback given in the first author's department is summarised next. In general terms the course receives excellent feedback for its resources, design and delivery.

1. Two 50min interactive lectures per week.
2. Weekly drop-in tutorials where students can get one-to-one assistance.
3. Three pass/fail (easy to mark) hardware laboratories supported by a number of optional virtual laboratories (due to very large numbers [circa 400], take-home laboratories cannot currently be used) to apply learning. Students not doing the compulsory preparation adequately are refused entry.
4. Regular short computer quizzes on the threshold learning elements. Students passing all the quizzes and laboratories achieve a bare pass. Higher marks are available through the end of year exam/assignments.
5. Use of a VLE to deliver all aspects of the course and including a discussion board which is checked daily.

Summary

The community has set out clearly [1, 19] the sort of content that should be in a first course and there is also a developing appreciation in the community of good pedagogy in a blended approach to course design and delivery. This brief paper has summarised some of those aspects concisely and the main call for the community now is to improve the efficacy of how we design and deliver such courses and moreover share good quality teaching resources to enable our colleagues to both find and use such resources efficiently. This will be a main focus of the IEEE TC on Control Education going forward.

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