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A First Course in Feedback, Dynamics and Control: Findings from 2019 Online Survey of the International Control Community

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Abstract: This paper summarizes the results from a large-scale survey on the content and teaching philosophy of the first, and in many cases the only, control course taken by undergraduate students in engineering and applied sciences around the world. The IFAC Technical Committee on Education developed and administered the survey in 2019. At the time of writing, 201 control professionals have responded to the survey. The majority view is that the first course in control should focus on concepts and avoid excessive mathematical proofs. The responders ranked the depth of coverage of 63 topics commonly found in introductory control texts. Based on the ranking results, a sample curriculum for a first control course is outlined.

Keywords: Engineering education, Automatic control curriculum, Introductory control curriculum

1. INTRODUCTION

Undergraduate students in many engineering and applied sciences programs around the world take only one control course. The instructors teaching this course are faced with a challenging task to design a syllabus that:

- Gives a broad picture of the field;
- Provides the right balance between fundamental theory and practical applications;
- Fosters technical skills relevant to industrial entry-level control positions;
- Accomplishes all of the above in a very limited time span, typically 40 contact hours of lectures, labs, and exercises.

Furthermore, some of the students in the course will enroll in subsequent control courses as electives. Thus, the course should also lay a solid foundation for successive, more advanced control courses.

Given the limited amount of time for the course, the most essential questions when planning the course content are:

- What topics to include and at what level of detail?
- What topics to exclude?
- What computational tools to use?
- How to assess students' understanding of the subject matter?
- How to motivate students and excite their interest and curiosity in control?
- What are the core competencies that industry expects for entry-level control positions for university graduates?

A number of publications and presentations during the past 15 years provide partial answers or individual opinions. Åström (2006), Atherton (2006), Leva (2019), and Rossiter et al. (2008) describe their experiences with teaching first control courses. Rossiter et al. (2014 and 2018) share a number of good teaching practices taken from a survey and from a group of experienced control instructors. Bajpai et al. (2016), Falsetti at al. (2006), and Dourado et al. (2012), give specific examples of control curricula in their countries. Bequette (2019) and Edgar (2006) provide a comprehensive account of control education in Chemical Engineering departments in the United States. Cook and Samad (2009) and Silverstein et al. (2016) present control curricula survey results. Heradio at al. (2016) discuss a survey on virtual and remote laboratories complementing control courses. Rossiter (2017) emphasizes the importance of connecting abstract control concepts to practical examples related to students' field of study. Alford and Edgar (2017), AIChE (2015), Alford (2006), and Shinskey (2002) address the gap between what is taught in academia and

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what is practiced in industry. Serbezov and Rice (2019), Hoernicke et al. (2017), Serbezov and Cummings (2016), and Bauer et al. (2014), provide examples of industrial engagement in control engineering education.

Despite the large volume of publications addressing various aspects of the introductory control curriculum, the control community still lacks a comprehensive up-to-date benchmark that reflects the collective view of control professionals, both from industry and academia, on the content and teaching methods in the first and only control course. In 2018, the leaderships of IFAC and IEEE Technical Committees on Education, EDCOM (2019) and IEEE TC (2019), in cooperation with the newly established IFAC Industry Committee, decided to develop and run a large-scale online survey related to the curriculum of the first and often only control course taken by engineering and applied science students. Realizing that the majority of students with bachelors and masters degrees take employment in industry, a major goal of the survey was to establish core competencies and key skills that industry expects for entry-level control positions.

In the first piloting phase, the survey was distributed to a limited group of 43 individuals, 31 from academia and 12 from industry. Feedback was sought on the topics to be included in the first control course, and on the design and administration of the survey itself. The results from the pilot were presented by Rossiter et al. (2019). The main takeaways were:

- Industrialists and academics largely agree on which topics are of secondary importance but there is a variation in opinions on the topics of utmost significance;
- A greater participation rate, especially from industry, is needed to support meaningful and credible results;
- The survey needed to be simpler in design.

The present paper presents the results from the revised large-scale survey released to the global control community in June 2019. The survey was promoted at a number of conferences and professional society meetings. The IFAC Industry Committee put a significant effort to reach out to its industrial base.

The authors hope that the results from the survey will be used as a global benchmark in control education around the world. The results are intended to be useful not only to those immediately involved in planning and delivering introductory control courses. They will be of interest to many others, especially from industry, who may benefit from an awareness of the entry-level engineers' competencies in control.

2. SURVEY DESIGN

From the point of view of establishing core competencies and key skills required by industry, the survey aims to be positively accepted by the entire control community. The survey is divided into several blocks described next.

2.1 Responder Background

When trying to establish a global benchmark, as well as to bridge academic and industrial views, the first important point is to achieve and track diversity. Participants were asked to clarify the basis for their views on the curriculum, by providing information about their age, geographical region, field of control application, and role. The results are presented in Fig. 1, and Table 1 to Table 3.

2.2 General Course Guidelines

This section asked for opinions related to the general course design, such as prerequisites, course hours, breadth vs. depth, and student assessment. The results are presented in Fig. 2 to Fig. 4.

2.3 Course Topics

In this section, a list of 63 topics typically included in introductory control courses, was provided. The topics were split into 6 groups:

- Signal Processing (4)
- Identification and Modelling (11)
- System Analysis (12)
- Control Design (24)
- Industrial Implementations (6)
- Tools (6)

The individual topics were rated on a 5-level Likert scale between "Cover in fine detail" and "Do not cover". Additional choices included "Cover primarily through a lab activity" and "Cover in a second / advanced course". The results are presented in Fig. 5 to Fig. 11.

2.4 Top Five Topics to Include

The participants were asked to rank in order the top 5 topics that should be included in the course. The results are presented in Fig. 12 and Fig. 13.

2.5 Survey Limitations

The international control community is extremely diverse. Individual views on control education depend on geographical region, field of application, affiliation with industry or academia, role within organizations, years of experience. The authors of the survey did not have control over the selection of participants. Thus, the responses have to be treated as a biased sample of the control community and the results have to be interpreted within the bounds of the responders' background.

3. RESULTS

3.1 Responder Background

A total of 201 responses to the survey were received between July and October 2019. The majority of the responses were from US and Europe (Table 1) by academics who have taught introductory control courses (Table 2). The total industrial representation was 15%. Most responders, 72%, were between 30 and 60 years of age with approximately equal distribution (Table 3).

Table 1. List of countries with 5 or more responses.

Country	Responses	% of Total
United States of America	47	23%
Spain	28	14%
Italy	26	13%
United Kingdom of Great Britain and Northern Ireland	15	7%
Germany	7	3%
Canada	6	3%
Chile	5	2%
Portugal	5	2%
South Africa	5	2%
Switzerland	5	2%

Table 2. Responders' counts by role.

Responders' Roles	Count	% of Total
Academic (taught introductory control recently)	116	58%
Academic (not taught introductory control recently	20	10%
Industrialist (regularly interacts with recent university graduates)	23	11%
Industrialist (does not regularly interact with recent university graduates)	5	2%
Researcher (university based)	30	15%
Researcher (not university based)	7	3%

Table 3. Responders' age distribution.

< 30	(31-40)	(41-50)	(51-60)	> 60
13%	23%	21%	27%	15%

The fields of control application influencing the responses are shown in Fig. 1. Electrical has the largest percentage, 16%. Chemical/Process, Mechatronics, and Systems follow closely. The top four fields account for 50% of the responses. There is not a clear bias related to one field.

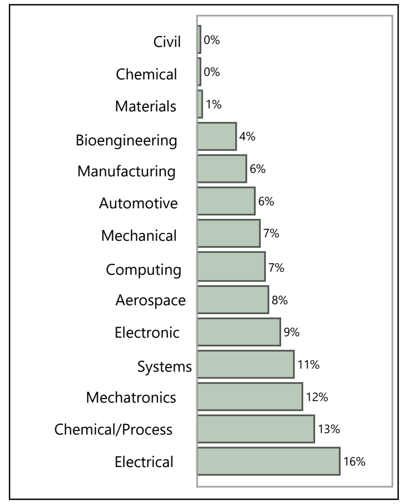


Fig. 1. Participants' fields of control application.

3.2 General Course Guidelines

Most of the responders, 55%, selected 40 to 50 lecture hours for the time expectations of the course (Fig. 2). This is consistent with a university schedule of 13-15 week at 3 contact hours per week.

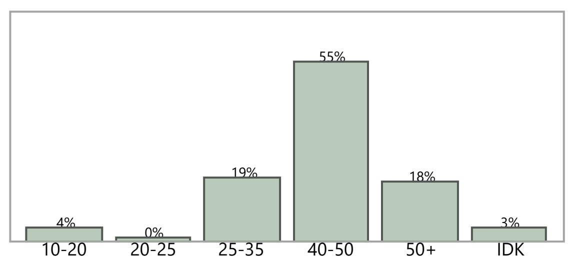
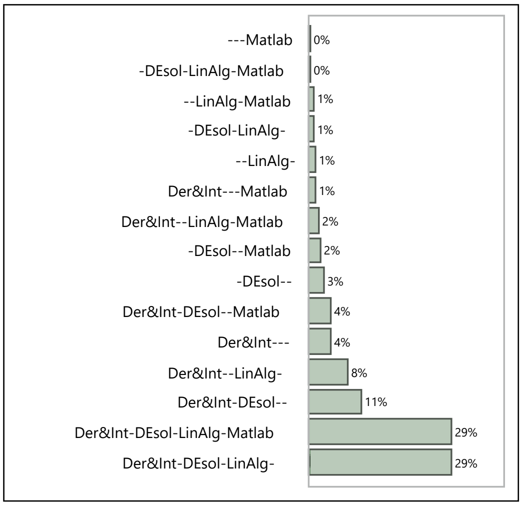


Fig. 2. Lecture hours expectations for the course.

The responses for course prerequisites are summarized in Fig. 3. Responders were allowed to select any combination of the four prerequisites, listed in the legend for Fig. 3. The majority of the responders, 58%, agreed that the three competencies listed below should be included as course prerequisites:

- Derivatives and integrals;
- Solution of differential equations;
- Working with matrices.

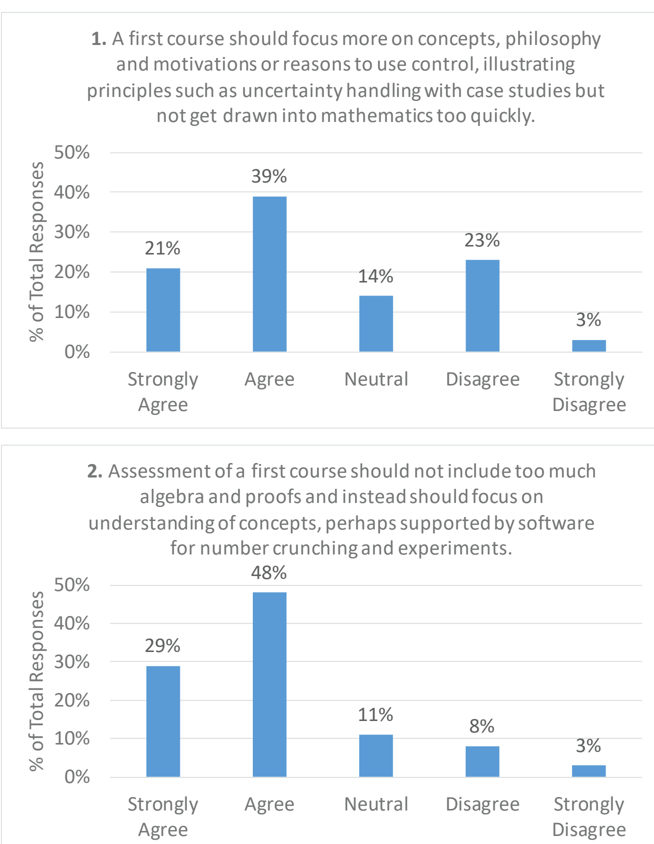
In addition, 29% of the responders thought that relevant knowledge of Matlab should also be added to the above three prerequisites.



Legend for Fig. 3:
Der&Int = Derivatives and integrals
DEsol = Solution of differential equations
LinAlg = Linear algebra (working with matrices)
Matlab = Relevant knowledge of Matlab

Fig. 3. Course prerequisites.

The choice of breadth and depth is essential in planning the first control course. A course could cover a broad selection of topics with lesser details, or alternatively, focus on a narrower scope of material and require deeper knowledge and mastery. The survey included six general questions related to this matter. The responses are shown in Fig. 4.



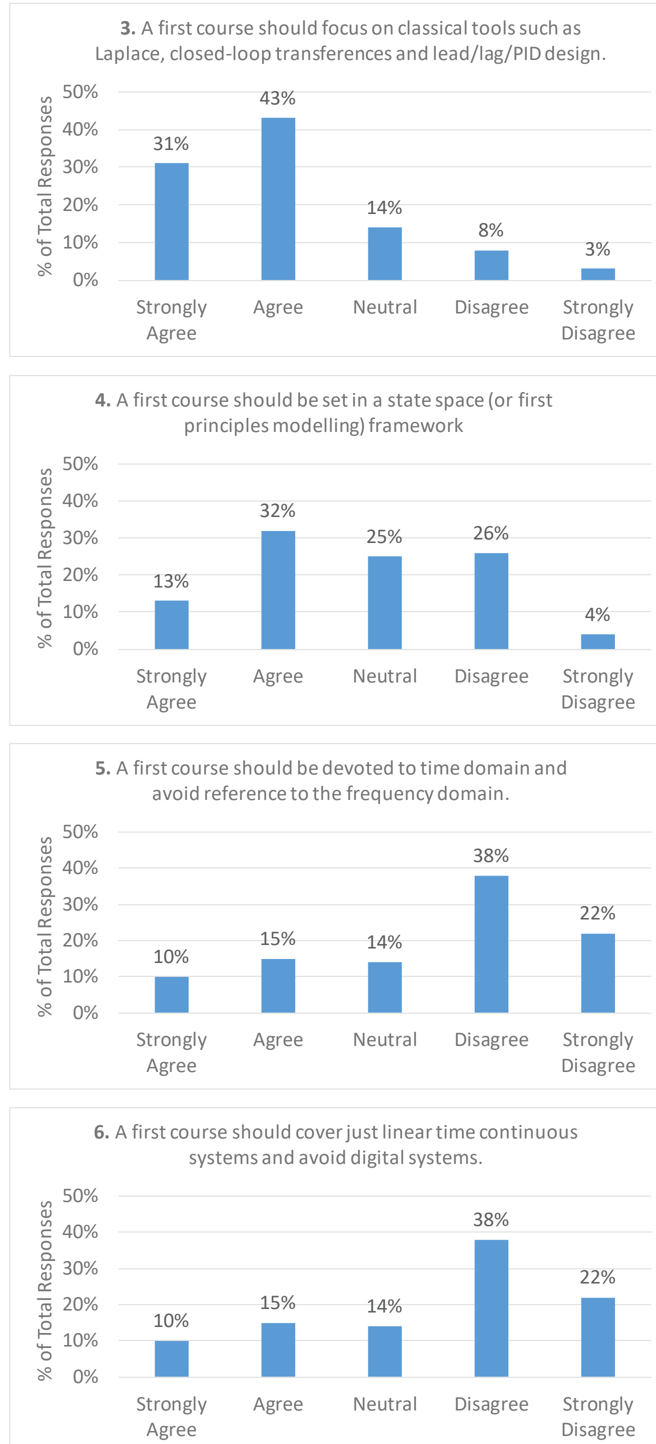


Fig. 4. Responses to general questions about the breadth and depth of the course.

The majority of the responders agreed that the course should put more emphasis on concepts rather than on mathematics, and be structured around classical tools, such as closed-loop transfer functions, Questions 1-3. Opinions were split on whether to set the course in a first principles framework, Question 4. There was a definite disagreement for excluding frequency domain analysis (Question 5) and digital systems (Question 6).

3.3 Course Topics Ranking

The responses for the level of coverage of course topics are summarized in mosaic plots, Fig. 5 to Fig. 11, and tables, Table A1 to Table A6. The tables are in the Appendix. The colour codes and response interpretations are given in Table 4. The ranking is based on a weighted sum calculated for each topic. The ranking scores are not shown in plots, but can be seen in the tables. The topics in the mosaic plots are ordered from left to right in descending order of the ranking score.

Table 4. Interpretation and weight factors for responses in Fig. 5 to Fig. 11.

Colour Code	Response	Interpretation	Weight Factor
	Fine Detail	Use precise mathematical analysis	+5
	Good Detail	Use some mathematical analysis	+4
	Minimal Detail	Use little or no mathematical analysis	+3
	Awareness Only	No detail or analysis	+1
	Lab Only	Cover primarily through a lab activity	+2
	Do Not Cover		-4
	Second Course	Cover in a second / advanced course	-2

3.3.1 Signal Processing

Results are presented in Fig. 5 and Table A1. Compared to other groups, the Signal Processing group of topics received moderate ranking scores. Results within the group suggest that the top two topics are (ranking score shown in parenthesis):

- Delays (187)
- Low pass filters (162)

3.3.2 Identification and Modelling

Results are presented in Fig. 6 and Table A2. Compared to other groups, the top four topics in this group received very high ranking. These topics are (ranking score shown in parenthesis):

- Modelling of simple, 1st and 2nd order systems (408)
- Block diagrams (396)
- Laplace and transfer functions (396)
- Models with integrating response (342)

3.3.3 System Analysis

Results are presented in Fig. 7 and Table A3. Compared to other groups, the top four topics in this group received very high to high ranking. These topics are (ranking score shown in parenthesis):

- Stability (403)
- Frequency response (317)
- Bode diagrams (297)
- Bode diagrams, gain/phase margins (294)

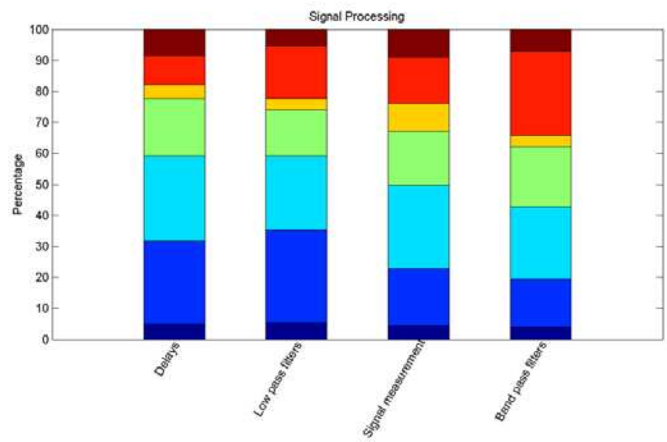


Fig. 5. Ranking of Signal Processing topics.

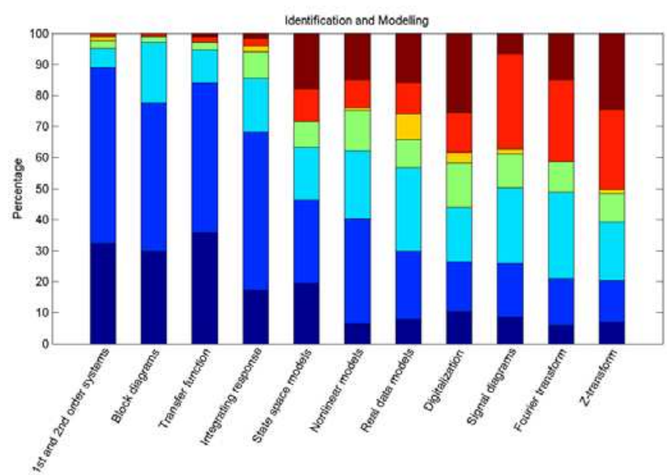


Fig. 6. Ranking of Identification and Modelling topics.

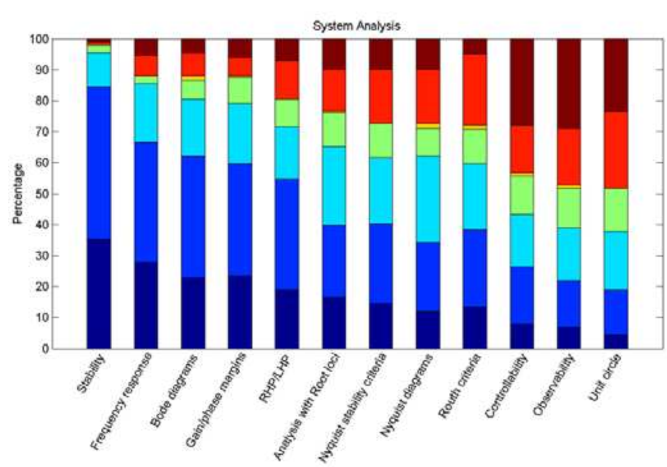


Fig. 7. Ranking of System Analysis topics.

3.3.4 Control Design

Results are presented in Fig. 8, Fig. 9, and Table A4. Compared to other groups, the top five topics in this group received very high and high ranking. These topics are (ranking score shown in parenthesis):

- Feedback loop concepts, definitions, and hardware components (436)
- PID (410)
- Control loop requirements (406)
- Control Performance (287)
- Disturbances (255)

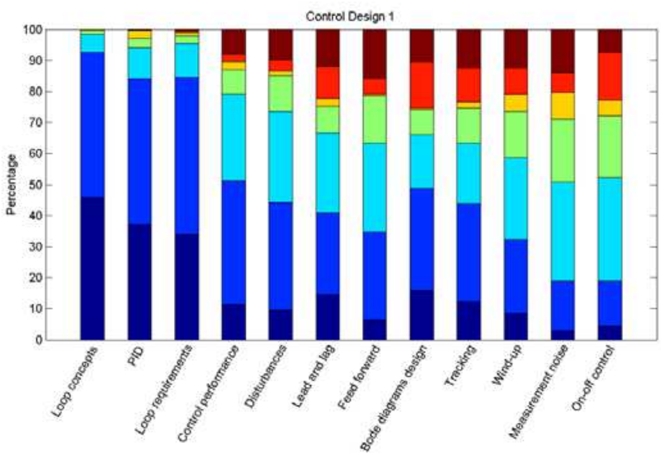


Fig. 8. Ranking of Control Design topics, 1 to 12.

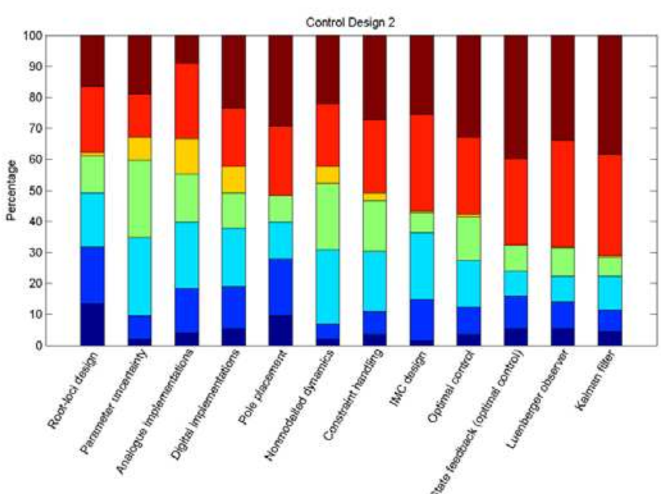


Fig. 9. Ranking of Control Design topics, 13 to 24.

3.3.5 Industrial Implementations

Results are presented in Fig. 10 and Table A5. Compared to other groups, the top two topics in this group received moderately high ranking. These topics are (ranking score shown in parenthesis):

- Control implementations (198)
- Hardware laboratories (196)

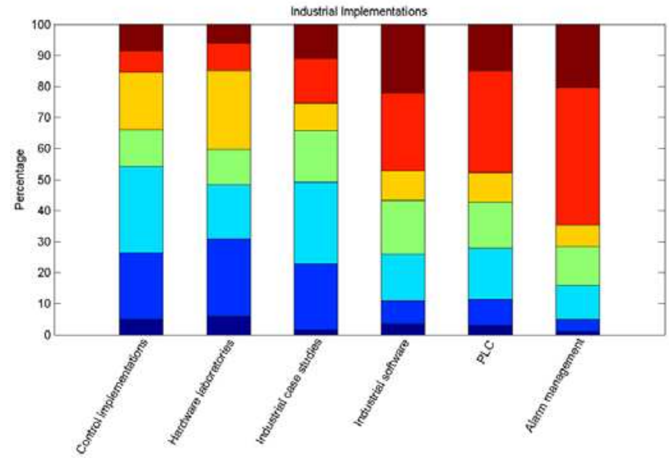


Fig. 10. Ranking of Industrial Implementations topics.

3.3.6 Tools

Results are presented in Fig. 11 and Table A6. Compared to other groups, the topics in this group received very low rankings with the exception of the first one:

- Matlab/Simuink (320)

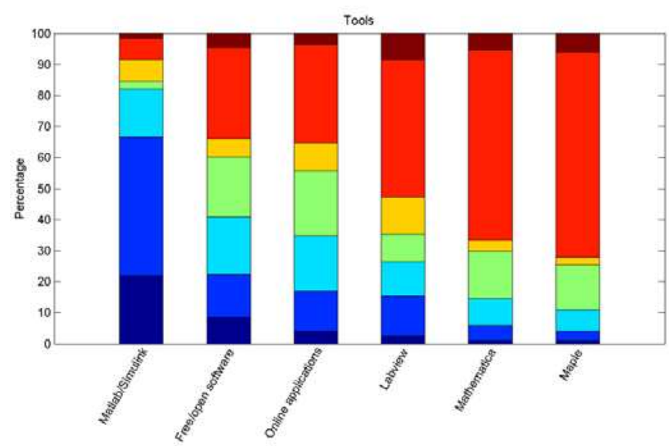


Fig. 11. Ranking of Tools topics.

3.3.7 Top Five Most Important Topics

The time constraints of the course will not allow covering all 63 topics listed in the survey. Inevitably, students will have a knowledge gap somewhere. But the first course in control is just the first stepping stone on the long road to mastering the subject matter. Thus, the goal of the first course should be to equip students with the most essential skills that will enable them to jump over the knowledge gap on their own. In that regard, responders were asked to list the top 5 most important topics in the curriculum.

Results are presented in Fig. 12, Fig. 13, and Table A7. An aggregate score was assigned to each of the selected topics by computing a weighted sum in which 5 points were given for first choice, 4 points for second, and so on.

Responders listed 14 topics in the top 5 category. Based on these responses, a model curriculum is suggested in Section 5.

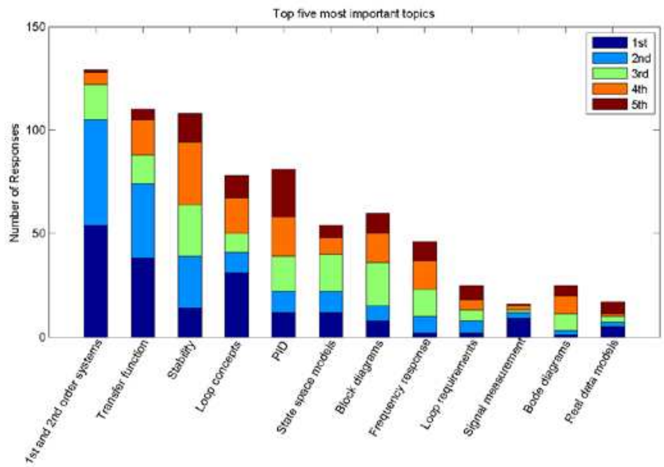


Fig. 12. Number of responses for the first twelve topics in the top five category.

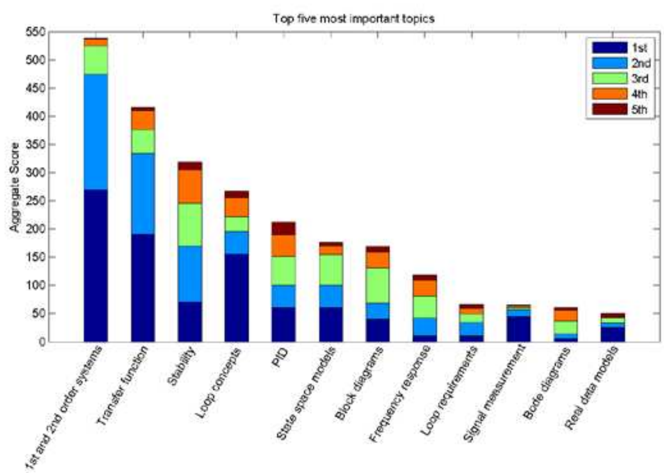


Fig. 13. Ranking of the first twelve topics in the top five category.

4. FREE RESPONSE COMMENTS

The survey responders were given two opportunities for free text entries where they could add additional comments and elaborate on their rationale for specific answers. In general, the comments reinforce the major findings in the survey and provide interesting individual perspectives. A few comments representative of the predominant sentiment are given below. A complete list of the comments can be found at http://iolab.sk/ifac/results.php.

The course philosophy is to focus on concepts. Motivation and rationale to study control need to be clearly articulated. At the end of the course, students should be able to recognize and appreciate the importance of control to safety and performance.

- *While some mathematics is essential, too much focus on this means that students may fail to grasp the significance of the topics and core concepts and instead would concentrate on memorising core procedures.*
- *A good course (and instructor) should be able to provide motivation and philosophy (the why) in addition to teaching methods grounded in mathematics.*
- *Students who come out of a first course in control theory with a solid understanding of the fundamentals are capable of learning what they "missed" as needed.*
- *If graduates are only going to do a single course in control, the maximum value is in awareness of the benefits of control for both performance and safety.*
- *A first course should include lab time, with industrial instruments and components if possible.*

There is a general agreement that due to time constraints some content cannot be included but the coverage can be expanded by adding prerequisites for the course.

- *My experience is that including digital systems results in too much material for a first course*
- *I found it is difficult to cover state space model, discrete control, and frequency analysis all in one control introduction course.*
- *Time domain is more broadly accessible, …., especially for chemical and biomedical engineering students.*
- *Also, given the prevalence of PID in industry it seems sensible to focus on that.*
- *I believe that some basic machinery such as differential equations, Laplace transforms, linear algebra etc should be outsourced to other course which can be placed as pre-requisites so that the students can dive into control systems/theory directly.*

5. EXAMPLE COURSE

This section summarises the philosophy and organization of the first and only control course, as supported by the majority view among the survey responders. The purpose of this section is not to prescribe a curriculum, but to collate the views of the international community as a guidance to individual instructors. It is understood that some readers may interpret the data slightly differently, or, due to local needs and context, come up with a slightly different list of priorities. However, we would conjecture that this proposal captures the core.

- Irrespective of which technical content is included, a first course should give a significant focus on concepts, motivation and case studies, helping students relate the topic to industrial need and practice.
- While some mathematical detail and rigour is essential and Laplace (transfer functions) is the preferred tool, a first course should not be too mathematically pedantic and theoretical; such things can come in later courses.

- First principles modelling and concepts/definitions of behaviours/performance measures are essential foundations alongside basic analysis tools such as block diagrams and stability.
- PID analysis, illustration and tuning should be included to some degree as this is the most common practice in industry.
- Use of appropriate software tools (MATLAB being most popular) to reinforce and apply learning is favoured. These can also be used to remove tedious number crunching from the assessment to allow more interesting questions.
- Some hardware laboratories should be included.
- Ideally a first course should go beyond just time domain and introduce some frequency domain and/or digital concepts.
- There is less consensus on the priority that should be given to more advanced tools such as root-loci, frequency response, lead/lag design, state space, signal processing and digital. The overarching viewpoint seems to be that students should not be overloaded and better that they appreciate the fundamentals well rather than misunderstand everything due to a focus on too much algebra. Your choice from these 'optional' extra topics is less critical, although Bode diagrams seem more preferred in the survey, and many can be covered in subsequent courses.

The following curriculum is suggested based on the top five rankings shown in in Fig. 12, Fig. 13, and Table A7:

- Signal Processing
    - Signal processing and impact of measurement (Awareness Only)
    - Delays and dead-time (Awareness Only)
- Identification and Modelling
    - Modelling of simple systems, 1st and 2nd order (Fine Detail)
    - Laplace and transfer functions (Fine Detail)
    - Block diagrams (Minimal Detail)
    - State space models (Minimal Detail)
    - Modelling from real data (Awareness Only)
- System Analysis
    - Stability (Good Detail)
    - Frequency response (Minimal Detail)
    - Bode diagrams (Awareness Only)
- Control Design
    - Feedback loop concepts, definitions, and hardware components (Good Detail)
    - PID (Good Detail)
    - Control loop requirements (Awareness Only)
- Tools
    - Matlab/Simuink

6. CONCLUSIONS

This paper provides a comprehensive up-to-date benchmark that reflects the collective view of the control community, both from industry and academia, on the content of the first, and in many cases, the only control course taken by engineers and applied scientists at the baccalaureate level. There is a consensus that for this course breadth is more important than depth. A few topics, however, such as transfer functions and simple systems, that form the very foundation of control, should be covered in fine mathematical detail. Knowledge of practical hardware as well as modeling from real data should be part of the curriculum. Both, time and frequency domain analysis should be taught. PID control should be covered in depth, while advanced control methods should be left for other courses.

The textual comments discussed in section 4 provide a wealth of information and insights about the trade-offs and challenges in teaching and planning the first control course. Both experienced and novice course instructors will benefit by reading them.

In section 5 the paper puts forward a sample curriculum that can be used as a starting point in course planning. Individual instructors can easily adapt it for their specific situations. The paper also provides a relative ranking of 63 topics commonly included in introductory texts. The rankings can be used to determine the relative importance of concepts when due to timing only a selected few could be covered in the course.

The results presented in this paper are based on 201 responses collected in the period July - October 2019. The survey remained open past that period, and the number of responses continued to increase. A future journal publication will include the additional data and will significantly expand the analysis.

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Appendix A. TOPIC RANKING DETAILS

Table A1. Level of coverage and ranking of Signal Processing topics.

Signal Processing Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Delays and dead-time	5%	27%	27%	18%	4%	9%	8%	187
Low pass filters	5%	30%	24%	15%	3%	17%	5%	162
Signal processing and impact of measurement	4%	18%	27%	17%	9%	15%	9%	134
Band pass filters	4%	15%	23%	19%	3%	27%	7%	55

Table A2. Level of coverage and ranking of Identification and Modelling topics.

Identification and Modelling Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Modelling of simple systems (1st and 2nd order)	32%	57%	6%	2%	1%	1%	0%	408
Block diagrams	30%	48%	19%	2%	0%	1%	0%	396
Laplace and transfer functions	36%	48%	10%	2%	0%	2%	1%	396
Models with integrating response	17%	51%	17%	8%	2%	2%	1%	342
State space models	19%	27%	17%	8%	0%	10%	18%	186
Nonlinear models and linearisation	6%	34%	22%	13%	1%	9%	15%	183
Modelling from real data	8%	22%	27%	9%	8%	10%	16%	162
Digitalization of the model and controller	10%	16%	17%	14%	3%	13%	25%	87
Signal flow graphs	8%	17%	24%	11%	1%	31%	6%	63
Fourier transform	6%	15%	28%	10%	0%	26%	15%	48
Z-transforms	7%	13%	19%	9%	1%	26%	24%	5

Table A3. Level of coverage and ranking of System Analysis topics.

System Analysis Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Stability	35%	49%	11%	2%	0%	1%	1%	403
Frequency response	28%	39%	19%	2%	0%	6%	5%	317
Bode diagrams	23%	39%	18%	6%	1%	7%	4%	297
Bode diagrams (gain/phase margins)	23%	36%	19%	8%	1%	6%	6%	294
RHP/LHP	19%	36%	17%	9%	0%	12%	7%	234
Analysis with Root-loci	16%	23%	25%	11%	1%	13%	10%	190
Nyquist stability criteria	14%	26%	21%	11%	0%	17%	10%	161
Nyquist diagrams	12%	22%	28%	9%	1%	17%	10%	155
Routh array/criteria	13%	25%	21%	11%	1%	23%	5%	143
Controllability	8%	18%	17%	12%	1%	15%	28%	61
Observability	7%	15%	17%	13%	1%	18%	29%	29
Unit circle	4%	14%	19%	14%	0%	25%	23%	5

Table A4. Level of coverage and ranking of Control Design topics.

Control Design Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Feedback loop concepts, definitions, and hardware components (closed-loop vs open-loop)	46%	47%	6%	1%	1%	0%	0%	436
PID	37%	47%	10%	3%	2%	0%	1%	410
Control loop requirements	34%	51%	11%	2%	1%	1%	1%	406
Control Performance	11%	40%	28%	8%	2%	2%	8%	287
Disturbances	9%	35%	29%	11%	1%	3%	10%	255
Lead and lag	14%	26%	26%	8%	2%	10%	12%	203
Feed forward	6%	28%	28%	15%	1%	5%	16%	196
Regulation and tracking	12%	31%	19%	11%	2%	11%	12%	193
Design with Bode diagrams (and/or frequency response methods)	16%	33%	17%	8%	1%	15%	10%	192
Wind-up and anti-windup	8%	24%	26%	15%	5%	8%	12%	184
Measurement noise	3%	16%	32%	20%	8%	6%	14%	158
On-off control	4%	14%	33%	20%	5%	15%	7%	133
Design with Root-loci	13%	18%	17%	12%	1%	21%	16%	89
Analogue implementations	4%	14%	21%	15%	11%	24%	9%	65
Parameter uncertainty	2%	7%	25%	25%	7%	14%	19%	62
Discrete time implementations	5%	13%	19%	11%	8%	19%	23%	44
State feedback (pole placement)	9%	18%	12%	8%	0%	22%	29%	17
Nonmodelled dynamics	2%	5%	24%	21%	5%	20%	22%	8
Constraint handling	3%	7%	19%	16%	2%	23%	27%	-21
Design with internal model control (lambda tuning)	1%	13%	21%	6%	1%	31%	25%	-43
Optimal control	3%	9%	15%	14%	1%	25%	33%	-51
State feedback (optimal control)	5%	10%	8%	8%	0%	28%	40%	-90
Luenberger observer	5%	8%	8%	9%	1%	34%	34%	-108
Kalman filter	4%	7%	11%	6%	1%	33%	38%	-118

Table A5. Level of coverage and ranking of Industrial Implementations topics.

Industrial Implementations Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Control implementations	5%	21%	28%	12%	18%	7%	8%	198
Hardware laboratories	6%	25%	17%	11%	25%	9%	6%	196
Industrial case studies	1%	21%	26%	16%	9%	14%	11%	127
Industrial control software (e.g. DCS systems)	3%	7%	15%	17%	9%	25%	22%	-17
PLC	3%	8%	16%	15%	9%	33%	15%	-29
Alarm management	1%	4%	11%	12%	7%	44%	20%	-138

Table A6. Level of coverage and ranking of Tools topics.

Tools Topics	% of Total							Ranking Score
	Fine Detail	Good Detail	Minimal Detail	Awareness Only	Lab Only	Do Not Cover	Second Course	
Matlab/Simuink	22%	45%	15%	2%	7%	7%	1%	320
Free/open simulation software	8%	14%	18%	19%	6%	29%	4%	58
Online control educational applications	4%	13%	18%	21%	9%	32%	3%	30
Labview	2%	13%	11%	9%	12%	44%	8%	-64
Mathematica	1%	5%	8%	15%	3%	61%	5%	-183
Maple	1%	3%	7%	14%	2%	66%	6%	-219

Table A7. Ranking of the top five most important topics.

Topics	Choice					Aggregate Score
	1st	2nd	3rd	4th	5th	
Modelling of simple systems (1st and 2nd order)	54	51	17	6	1	538
Laplace and transfer functions	38	36	14	17	5	415
Stability	14	25	25	30	14	319
Feedback loop concepts, definitions, and hardware components (closed-loop vs open-loop)	31	10	9	17	11	267
PID	12	10	17	19	23	212
State space models	12	10	18	8	6	176
Block diagrams	8	7	21	14	10	169
Frequency response	2	8	13	14	9	118
Control loop requirements	2	6	5	5	7	66
Signal processing and impact of measurement	9	3	1	2	1	65
Bode diagrams	1	2	8	9	5	60
Modelling from real data	5	2	3	1	6	50
Delays and dead-time	1	2	3	1	4	28
Matlab/Simuink	0	1	1	3	15	28