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Agile Process Systems Engineering (PSE) education – 2. How to teach to achieve desired outcomes mastery by graduates

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Abstract

This study is the second part of a contribution addressing the appropriate content of process systems engineering (PSE) curriculum (the "what") and how best it should be taught, so that our graduates are equipped to effectively apply their knowledge (the "how"). The two-part contribution presents the collective views and perceptions of the responders from all over the world to surveys as well as the collective view of the authors. This paper presents the "how" – how best to instruct our students in all matters PSE, given the availability of teaching technologies, and the time available to effectively train our students.

Keywords: PSE education, curriculum, active learning.

1. Introduction

This two-part paper proposes a "game plan" for effective teaching of process systems engineering (PSE) topics that addresses *what* should be taught and *how* these topics should be taught effectively. We base our recommendations on: (a) A survey of the teaching methods used by professors teaching PSE concepts and tools in universities around the World (the "how"), and (b) Surveys of the actual topics and application areas covered in the courses taught in academia (the "what"). This second part concerns the "how" – the most effective methods that should be used to achieve learning objectives that enable graduates of the first degree in chemical engineering – either a Bachelor's, but in many cases, a Master's degree. In particular:

- Students should be taught fundamental concepts in detail, ideally self-paced. This is achieved more efficiently using prerecorded materials.

- Students need to be exposed to computer programming packages ranging from those solving chemical process flowsheets to those specialized in data analysis, optimization, and spreadsheets.
- Students need to understand why some software or computer packages may not provide accurate answers in some instances. The fact that they run and converge to a solution does not necessarily mean that the solution is correct.
- Students should become familiar with optimization tools earlier in their academic career, so that they can use them to solve practical problems in their senior years.
- Students should apply multivariate statistical and artificial intelligence tools for solving real problems.
- Students should be required to develop critical thinking skills, i.e., to question their solutions/methods and ask themselves if other (attractive) approaches could be used to tackle a particular problem.
- Students should develop professional and personal skills such as teamwork, communication, project management.

This study consists of a survey of teaching practices aimed to assess the degree to which active methods are used in practice, to understand their benefits, limitations, and potential reasons as to why they are not implemented, and to identify circumstances or the conditions under which these methods may be more effective. The two-part paper provides a working plan for academic activity in preparing the next generation of engineers and researchers to be better aligned with the needs of both academic research, industry, and society, without requiring additional time-on-task beyond that allocated currently for the coverage of PSE topics.

2. Teaching PSE using Active Learning

For students to attain mastery in the critical understanding and application of the PSE core materials, time needs to be allocated for them to experiment, get things wrong and understand why; thereby, repeating this process as many times as needed. Such student-centered, active approaches to learning require time, which in a conventional teacher-centered approach is often allocated to lecturing. Several methods have been advocated that free class time for students to engage in active learning such as project-based learning, blended teaching, and flipped class approaches. The flipped class paradigm, detailed by Lewin (2022), moves the transmission of basic information to online preparatory tasks, which students complete in advance of class activities. This freed class time enables the four key agile values to be incorporated into the class environment, i.e.,

1. Student-centered flipping inherently focuses on the learner rather than following traditional teaching processes, which are teacher-centered.
2. Student-staff contact time is mostly used to work problems cooperatively and for project work, rather than for the transmission of information.
3. The contact time is largely reserved for collaborative work between staff and students and transforms the staff member to take on the role of mentor and motivator.
4. Staff can respond to the feedback and needs of students.

3. Method

3.1. Design

We used a survey to map the teaching perceptions of PSE academic teachers around the world. The survey asked the responders to establish their position regarding the application of active teaching methods, and then describe the extent to which active

methods are used in one of the courses taught by the responder. Moreover, the responders were asked to discuss how they see their teaching will evolve, and to define barriers to future evolution of their teaching approaches. This questionnaire was termed the "HOW" survey, delivered using Google Forms, and distributed to the global PSE community.

3.2. Material

The survey consisted of 26 questions organized into five main categories:

A. Information about the responder (i.e., geographical location, teaching experience)
B. Questions regarding the responder's position on aspects of the PSE curriculum
C. Questions regarding the responder's position on how teaching should be carried out and, to the degree to which active learning should be applied.
D. Questions regarding the responder's teaching practice, and to what extent active learning is employed.
E. Questions regarding the responder's future adaptation of teaching methods.

3.3. Participants

To cover as many individuals as possible, we reached out to the following communities: the EURECHA members, the Energy Section of the EFCE, the AIChE CAST mailing list, the CACHE mailing list, the master list used to promote PSE 2018, the Canadian Systems and Control Division mailing list, and the Japanese PSE community.

3.4. Procedure

On 15th October 2021, a request for feedback with a link to the survey was emailed to all potential responders on the mailing lists described above, with a reminder sent on 22nd October. We received 82 responses from academic lecturers from all over the world, with the following geographical distribution: 47.6% Europe, 20.7% North America, 15.9% Asia and 13.4% Central/South America. Most of the responders (83%) had more than 10 years of experience teaching PSE courses, with an additional 10% having between 6 and 10 years of experience.

4. Analysis

The responses to the 18 questions establishing the positions of responders in Parts B-E (see Section 3.2) were distributed on a 5-point Likert scale (1 indicates strong disagreement, 3 indicates a neutral position and 5 indicates strong agreement). Tables 1-4 summarize the averages and standard deviations and presents histograms of the received responses to the position questions.

Table 1. Statistics and response distributions of the received responses to the position questions of the "how" survey, **Part B: Your position on aspects of the PSE curriculum.**

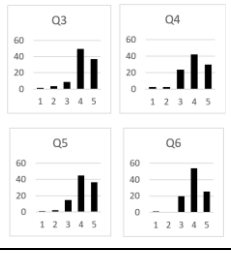
Question	Question statement	Ave	STD	Histograms
Q3	Enrich Courses should be enriched with external sources or guest lecturers	4.17	0.83	
Q4	Should offer courses using open access software	3.94	0.93	
Q5	Should offer courses on advanced statistics	4.13	0.84	
Q6	Should offer courses on AI and ML	4.02	0.75	
Summary: There is general agreement about the need to enrich PSE courses using external sources (Q3), and to maintain curriculum up-to-date with regards to the usage of open-access software (Q4), and the introduction of courses in advanced statistics, artificial intelligence, and machine learning (Q5 and Q6).				

Table 2. Statistics and response distributions of the received responses to the position questions of the "how" survey, **Part C: Your position on how should teaching be carried out in practice**.

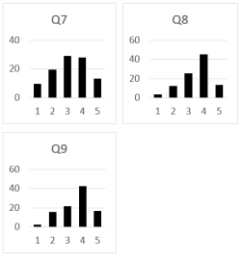
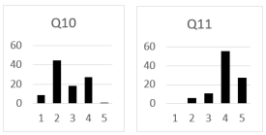
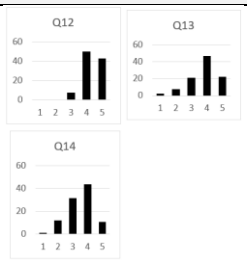
Question	Question statement	Ave	STD	Histograms
How course materials should be transmitted to students, and how best to utilize contact time				
Q7	Classes should be organized so teachers mostly lecture, and students listen	3.16	1.18	
Q8	Lecture materials should be reviewed by students on their own as homework in preparation for class activity	3.52	1.00	
Q9	Most of the contact time between teachers and students should be used for student activity	3.56	1.03	
The responses indicate ambivalence regarding face-to-face lecturing as the main transmission vehicle (Q7). There is slightly more support for moving materials online for students to cover on their own (Q8) and for class time to be used more for student activity (Q9). However, it is fair to indicate that this support was not overwhelming.				
How should most of recitation time be best utilized?				
Q10	Instructors demonstrating solutions and students listening	2.68	1.01	
Q11	Students solving problem sets with staff providing hints/motivating	4.04	0.80	
If responses are consistent, the two questions should have response distributions that are mirror images. The responses to Q10 are bimodally distributed, with more disagreement than agreement – more responders do not approve of student passivity, but clearly many are comfortable with it. Moreover, Q11 indicates that there is strong support of student activity in recitations. However, the distributions are clearly not inversed, as they should be for consistency.				
How should PSE course outcomes be assessed?				
Q12	Include a significant portion of project-based learning (teamwork)	4.35	0.62	
Q13	Students should do individually graded homework exercises	3.79	0.96	
Q14	Using one or more exams involving open-ended problem solving	3.51	0.89	
The need for project-based assessment (Q12) received strongly positive response. There were mixed feelings about the other two issues – while there is a slightly positive position regarding the need to check individual students' formative abilities by grading homework (Q13), the position does not have overwhelming support. The support for summative assessment (exams, Q14) is moderate. The main issue is which kind of formative/summative assessment methods are the most appropriate given students' time limitations. What proportion of assessment should be team or individual is crucial. That is likely to be more significant than the methods.				

Table 3. Statistics and response distributions of the received responses to the position questions of the "how" survey, **Part D: How do <u>you</u> teach?**

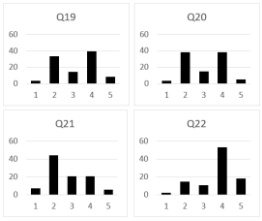
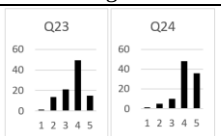
Question	Question statement	Ave	STD	Histograms
Q16	Graduate (G) or undergraduate (UG) course: 28% UG, 53% Combined, 19% G			
Q17	Subject taught: 48.5% Process design, 33.3% Process control, 15.2% Optimization, 3% Numerical methods			
Q18	Class size: : 8.6% <10, 58% 10-50, 25.9% 51-100, 7.4% >100			
Slightly more than half of the responders teach mixed classes of graduate and undergraduate students, with 28% teaching only undergraduates and 19% teaching only graduates. Most responders are teaching either process design (49%) or process control (33%). Most class sizes are either medium-sized with 10-50 students (58%) or large with 51-100 students (26%).				
The following questions were directed at the type and mode of learning environment that exists in the responders' institution.				
Q19	Student-centered (>50% of contact time is student activity).	3.16	1.10	
Q20	Teacher-centered (>50% of contact time, students are listening to me).	3.02	1.06	
Q21	Students are required to work independently and not in groups.	2.74	1.07	
Q22	Student activities are included into the lectures and recitations.	3.70	1.02	
The responses to Q19 and Q20 regarding how responders run their lectures are very similar and are both bimodally distributed. The responses are almost split 50/50 between those who teach in the traditional teacher-centered method (teacher talks – students listen) and those who apply student-centered, active learning in their classes. More detailed analysis indicates that much of the support for student-centered activity was by teachers of process design, and independent of the class size. Q21 discloses the responders' views on the need for students to work independently rather than in groups. The majority of the responders disagree with this statement, indicating there is some application of group effort in many of the responders' courses. However, many of them (27%) still consider it important for students to spend time working problems on their own. Q22 discloses the responders' choice to include student activities into lectures and recitations. The responses to this question are somewhat in conflict with the responses to Q19 and Q20. On the one hand, about 50% of the responders adopt teacher-centered classes, yet here there appears to be more than 50% support for student-centered class activities. Perhaps the question was poorly posed as it refers both to lectures and recitations.				

Table 4. Statistics and response distributions of the received responses to the position questions of the "how" survey, **Part E: Your position on adaptation of teaching methods.**

Question	Question statement	Ave	STD	Histograms
Q23	I regularly investigate the engineering education literature	3.63	0.94	
Q24	It is important that I increase my use of real-world situations	4.12	0.87	
The surprising response to Q23 indicates relative support for keeping in touch with state-of-the-art engineering education literature, while Q24 indicates strong support for increasing use of real-world situations in the classroom.				
Q25	Most important barriers for me to innovate in my teaching role	65%	Time taken away from research activities	
		46%	Lack of available institutional funding	
		32%	Student dissatisfaction with new methods	

5. Responder Opinions Summarized and Conclusions

Lecturers are ambivalent concerning whether teacher-centered instruction is appropriate (Q7) but tend to support the idea of students reviewing materials to prepare for class (Q8) as well as the use of contact time to enable student activity (Q9). Regarding recitations, the responders largely disagreed that staff should run them in demonstration mode (Q10), and strongly supported the idea of active tutorials, where students do the problem-solving themselves (Q11). Regarding outcomes assessment, there was high agreement that project-based learning (PBL) should be employed (Q12), agreement that individually graded homework should be assigned (Q13), and that open-ended exams should be used for formative assessment (Q14). Note that requiring both preparation before classes, as well as individual homework and project work may overload students, and this needs to be considered. When it comes to their own teaching practice in lectures, the responders were more ambivalent, with responses almost evenly split between those taking teacher- and student-centered approaches (Q19 and Q20). Regarding student activities, there are more instances of group work than individual work (Q21), and a majority of the respondents include student activities in lectures and recitations (Q22). Furthermore, the responders indicated that a majority regularly update their teaching materials (Q23), and a large majority indicated the importance of using real-world situations in their teaching, which links to the importance of PBL indicated by Q12. Finally in addition, the main obstacles to teaching innovation (Q24) are identified as the lack of time (65%), followed by the lack of institutional support (46%), but it also appears that not all students are welcoming innovative teaching methods (32%). In addition to the above, the survey also included two questions (Q15 and Q26) giving responders the opportunity to make general remarks. Because of space limitations, these are not being addressed in this paper, but will be summarized in the full version, as will summaries of interviews with leading members of the worldwide PSE community.

The survey disclosed that there is a gap between the technological capabilities that can be harnessed to the teaching of PSE and practice for many of the responders, most of whom see this as a burden since research time is sacrificed to perform this activity. Perhaps additional incentives are required to promote the move to more active teaching. In conclusion, the objectives of our studies are to provide information and suggestions to improve learning outcomes (i.e., the “what”) but also their efficient transmission to students (i.e., the “how”). The process systems engineering community needs to openly share best practices and resources, otherwise we will be back talking on this subject in 5- or 10-years' time (Cameron and Lewin, 2009, Cameron et al., 2019, Kiss and Grievink, 2020).

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