CACHE/ASEE Survey on Computing in Chemical Engineering

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Introduction

CACHE (Computer Aids for Chemical Engineering) Corporation has conducted a survey in 2019 on computing in chemical engineering education and industry. Previous surveys were conducted by CACHE of chemical engineers working in industry in 1997 and 2003. In these surveys most of the questions pertained to chemical engineers working in industry with a limited number of questions related to what chemical engineers were taught at universities. In 2001 a survey was conducted on computing practices in process simulation in chemical engineering education at universities [1]. For the 2019 survey CACHE surveyed both chemical engineers in industry and what faculty were teaching at universities. The purpose of the survey was to determine current computing needs for industry and academia. A secondary purpose was to compare the findings relative to the previous surveys, although because the survey questions were updated, a direct comparison was not possible for all questions.

In the industrial survey we used the web based survey software from Survey Monkey. Using this software, weblinks were sent to alumni from RPI, Rowan, Brigham Young, Notre Dame, Georgia Tech and North Carolina State universities. This is similar to what was done for the 1997 [2] and 2003 [3,4] surveys. For example, in the 2003 survey the participating universities were Carnegie Mellon, Clarkson, McMaster and Texas at Austin Universities. In the current survey we also expanded to chemical engineering graduates from other universities by posting web links on sites such as Linked-In and Facebook. All of these communications contained a link to the Survey Monkey web site in which a series of questions were presented to chemical engineers working in industry assessing their computing practices, which resulted in 413 responses.

The Survey Monkey software was used as the vehicle to collect and analyze the survey results which allowed us to improve and update the original survey questions. For example, several questions were dropped that had little relevance to today's use of computers. These included questions on the fraction of the day at the computer, computer usage for word processing, email, spreadsheet and presentation software. In addition several questions were transformed from a yes or no answer to a Likert scale with 5 divisions. This resulted in a more quantitative response to a question instead of a simple yes or no answer. In comparing the current survey to previous surveys, several of the Likert scale questions were converted to the scale used in the 1997 and 2003 surveys.

The 1997 and 2003 surveys were only sent to alumni of universities and only a few questions were asked about computing education at universities. In this survey we asked professors an extensive set of questions on what computing tools are currently being taught and used in the chemical engineering curriculum at universities. This email was originally sent out to the chemical engineering chairs/heads and was then distributed to faculty in their departments. Instructions were sent that multiple faculty could answer the survey, but in many departments only one response was sent back per department. The final result from these survey requests resulted in 154 responses from 70 chemical engineering departments. Since this is a new survey there isn't a direct comparison with the previous surveys, but we have made comparisons with the previous alumni results and the professor's answers when appropriate.

Computing in Industry

The 307 respondents to the industrial survey were divided between about 1/3 having PhD degrees and 2/3 having BS degrees as the highest degree. Similar to the previous surveys in 1997 and 2003, their job roles were evenly represented among Research & Development (25%), Plant and Process Support (18%), and Process Design and Analysis (29%), with other roles also represented. The respondents with PhDs had more years of experience (35% over 21 years), while those with a BS degree tended to have less experience (45% less than 5 years).

After the initial questions on the background of the respondent, the first question asked, "which of the following is most appropriate for your industry?" Using computer applications was the most important computing tool for industry with over 60% choosing this option. The other options of statistics/analytics, programming, and machine learning were ranked as less important.

As seen in the 1997 and 2003 surveys nearly all chemical engineers use spreadsheet programs, and this finding was confirmed in this survey. In this survey we asked what were the major uses of spreadsheet programs and for each category shown in Figure 1. In each of these categories, respondents rated the use from 5 (high) to 1 (low) with an additional option to state if spreadsheets were not used for this category. In Figure 1 the average score for this rating is shown. To compare this question to the 2003 survey in which only a yes or now response was obtained, we grouped the 4 and 5 responses to indicate a yes. Using this criteria, spreadsheet software is used by 70% of respondents for process data analytics, as well as economic studies (38%), engineering design (36%), material and energy balances (28%) and numerical analysis (13%). Using this basis the two surveys are similar with the exception that in 2003 process data analytics was even higher (88%), and numerical analysis was substantially higher (47%). It was interesting to note that about 1/3 of respondents in the 2019 study did not use spreadsheets for numerical analysis and material and energy balances.

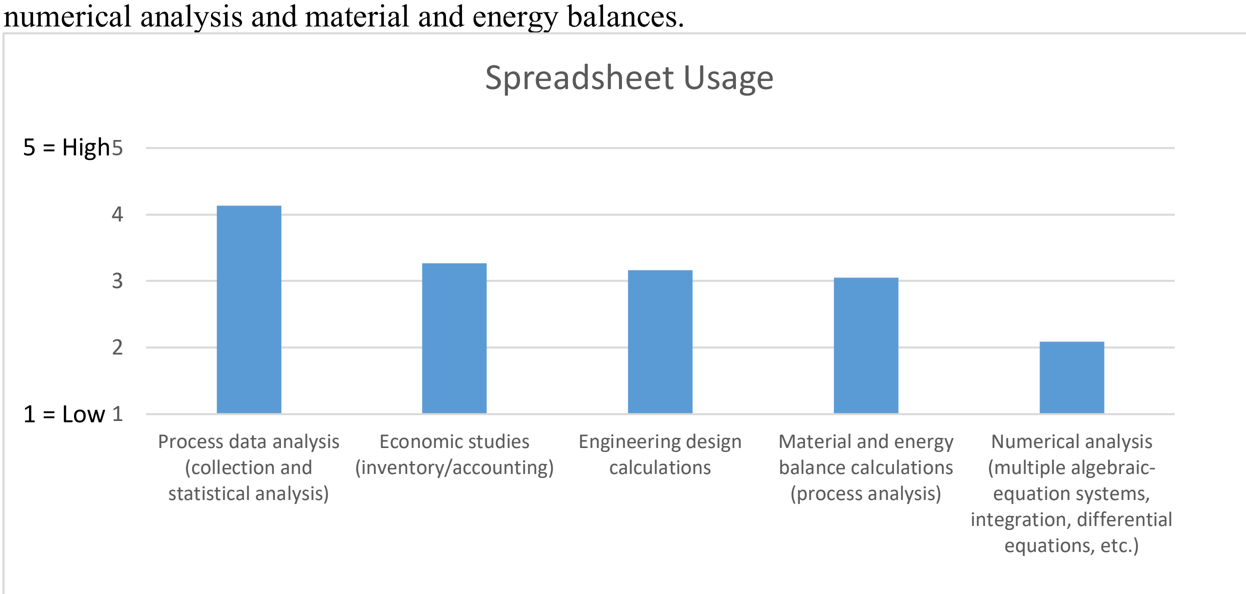

Figure 1: Resulting average rankings by the respondents to the industry survey question, "Please rank the primary tasks that require the use of spreadsheet software."

The next question was asked to determine what types of software packages (excluding process simulators) are used by chemical engineers at work with results shown in Figure 2. The most commonly reported software packages used in industry were database management systems, with over 60% of respondents indicating their use in both 2019 and in 2003 (see Figure 2). In 2003, other types were indicated at levels below 30% (statistical analysis, numerical analysis, symbolic manipulation, numerical methods libraries). However, in 2019, 60% of respondents indicated that they are using dedicated statistical analysis software, and 38% are using numerical analysis software. The notable increased use in statistical analysis software may be consistent with overall heightened interest by industry in data analytics and machine learning [5].

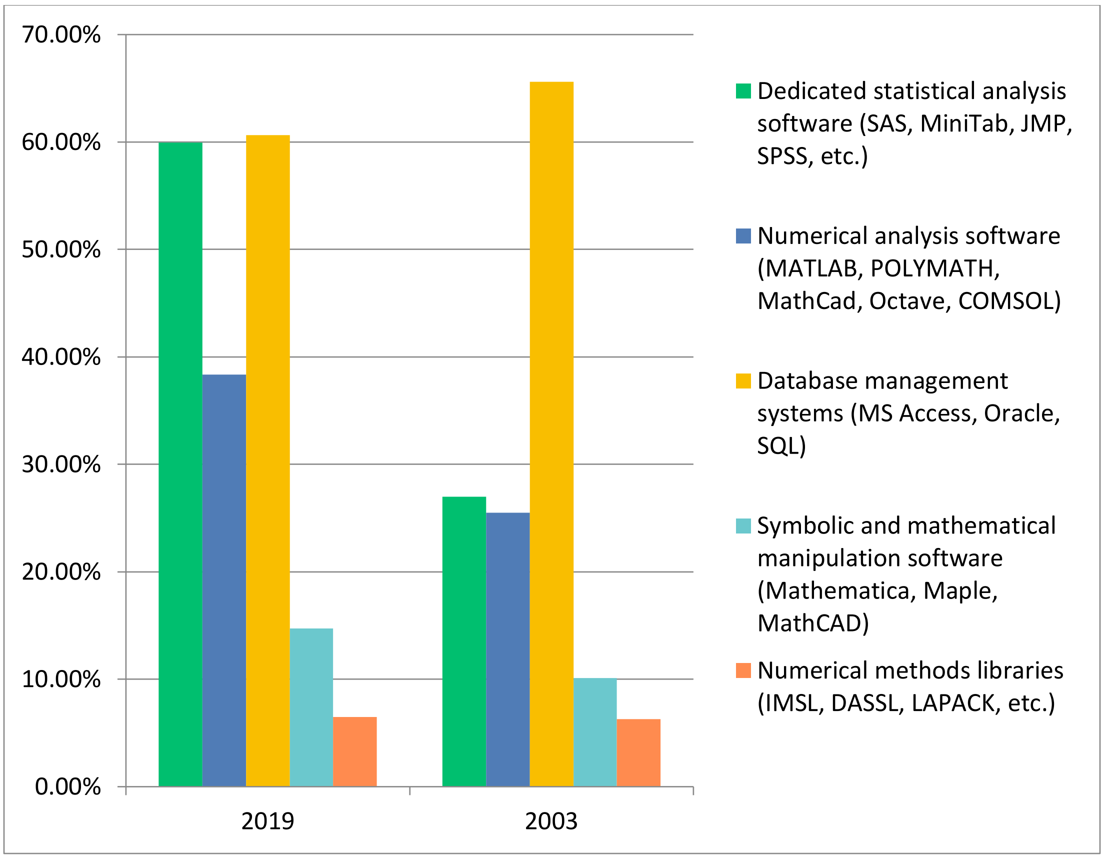

Figure 2: Reported use of software packages in 2019 and in 2003.

As shown in Figure 3 process simulators are not used by the majority of respondents (> 60%) in 2019, and similarly in 2003 (> 50%). However, process simulators are used by about a third of the respondents, with AspenPlus and AspenHysys being the two most commonly used programs, similar to 2003. About half of the respondents (56%) reported that they were adequately educated at their university to use and understand chemical process simulation programs, similar to 2003 (49%). In both surveys about 20% indicated that they were not adequately trained.

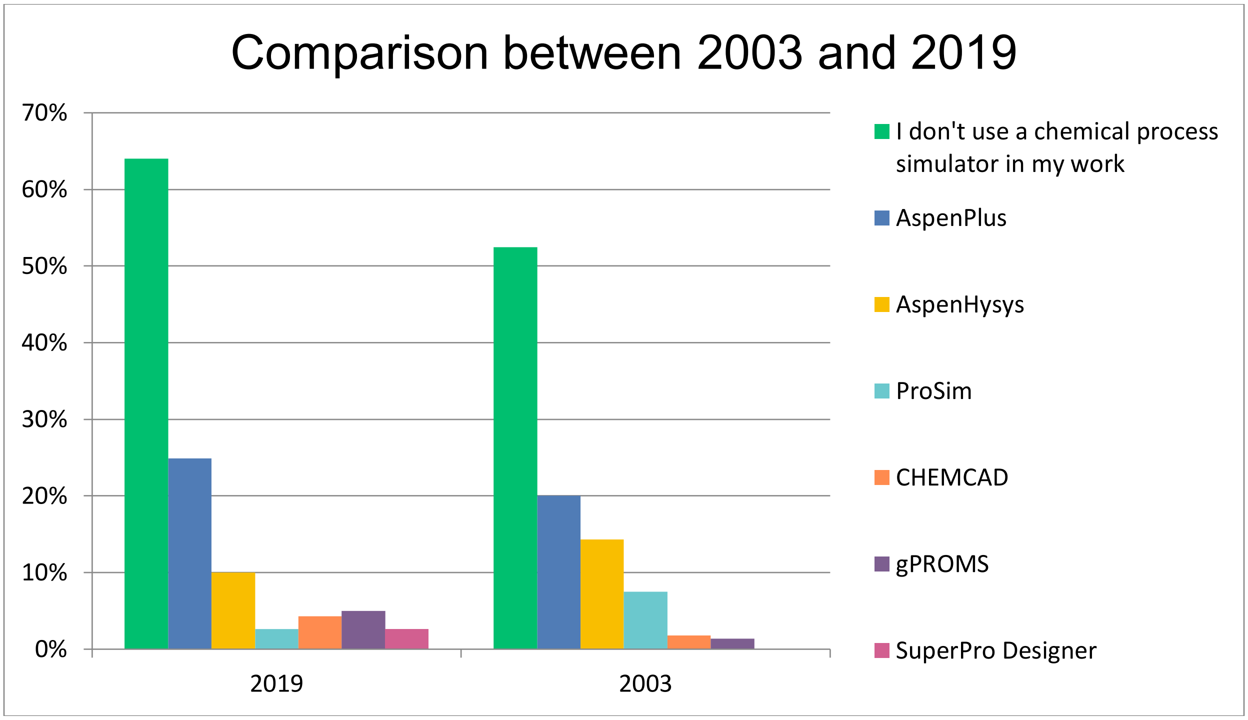

Figure 3: Do you use a chemical process simulator and, if so, which software package(s) do you use? (multiple answers allowed)

Respondents were asked how they are trained to learn new software programs. Similar to 1997 and 2003, the most reported method is "self-taught," followed by "colleagues," and then "company-provided training." A detailed summary of methods is shown in Figure 4.

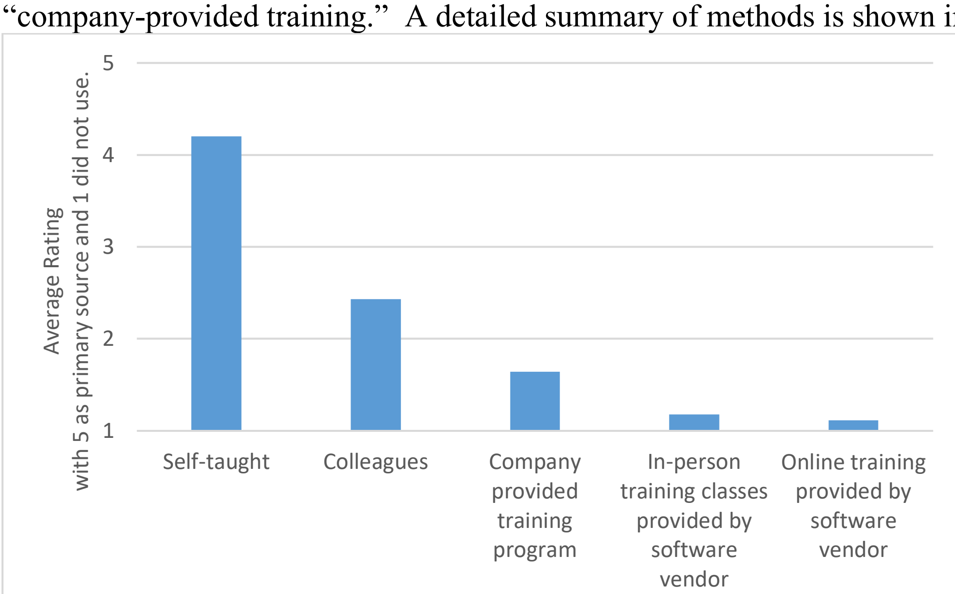

Figure 4: When training is required for a software program, rate the training method that you used. With 5 as Primary Source and 1 did not use this training method or it was not available.

While most respondents do not place programming as their most important tool, of those that do, Python was the most common language (24%), followed by MATLAB (21%) and VisualBasic

(17%). Certainly this is a change from the 2003 survey, in which Python wasn't one of the language options in the survey. Education and training in Python is appropriate, given this primary position in industrial use.

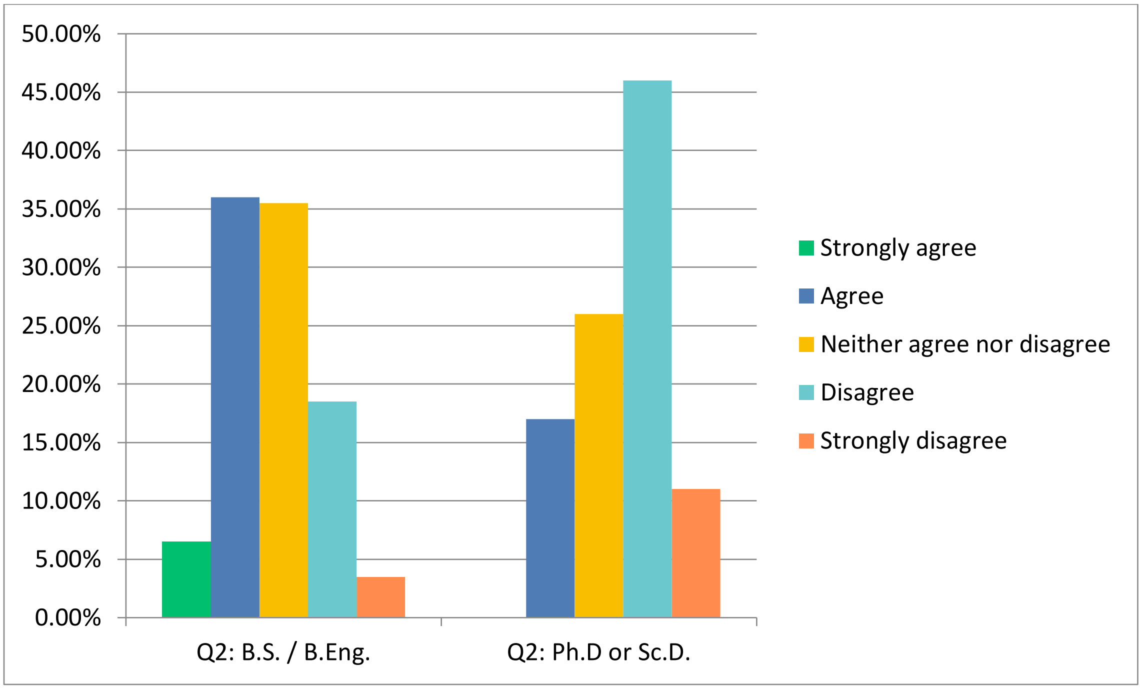

Figure 5: How strongly do you agree with this statement? "Your new chemical engineering hires have sufficient education in statistics and data analytics."

Finally, respondents were asked if the new hires at their company have sufficient education in statistics and data analytics. Some respondents agree while others disagree, as shown in Figure 5. At the BS level, the responses were more mixed, while at the PhD level, 57% either disagreed or strongly disagreed with this statement. This response could be related to the level of knowledge of statistics and data analytics with Ph.D's expecting a higher education level.

Computing in Education

The methods used to teach computing to chemical engineering students have evolved from the time that all engineers were required to take a programming course taught by the computer science department. Today, the majority of chemical engineers are learning programming in courses taught in chemical engineering (59%) and not in computer science (33%) as shown in Figure 6.

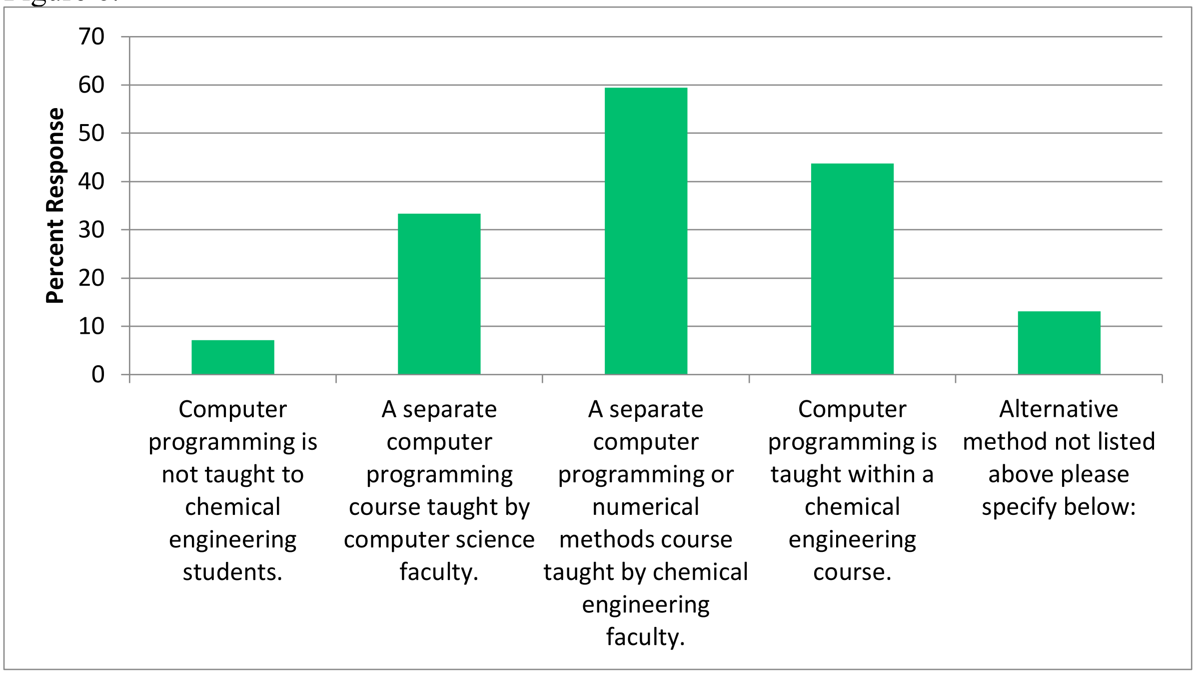

Figure 6: Academic Survey: "Is computer programming taught to your chemical engineering students? (select all options that apply)"

The predominant programming language taught is MATLAB (78%) followed by Python (31%) and then Visual Basic (15%). This is a notable change compared to the 2003 survey in which Visual Basic was the top recommended language (33%) and Python was not an option. This question had an extensive list of 19 possible programming languages with an option to specify a language that was not listed.

Questions about statistics and data analytics were asked in this survey that were not in previous surveys. Currently statistics or data analytics are required subjects for chemical engineers at most universities. Students take these subjects primarily in a required course taught by chemical engineering faculty (59%) compared to a required course outside of chemical engineering (24%). In the comments to this question there were many departments that taught statistics in a laboratory course such as unit operations (25 out of 93). What was not ascertained in this survey was the statistics topics that were taught in these courses. Perhaps a future survey on this subject should be conducted to determine what is taught in universities and what topics are used by industry.

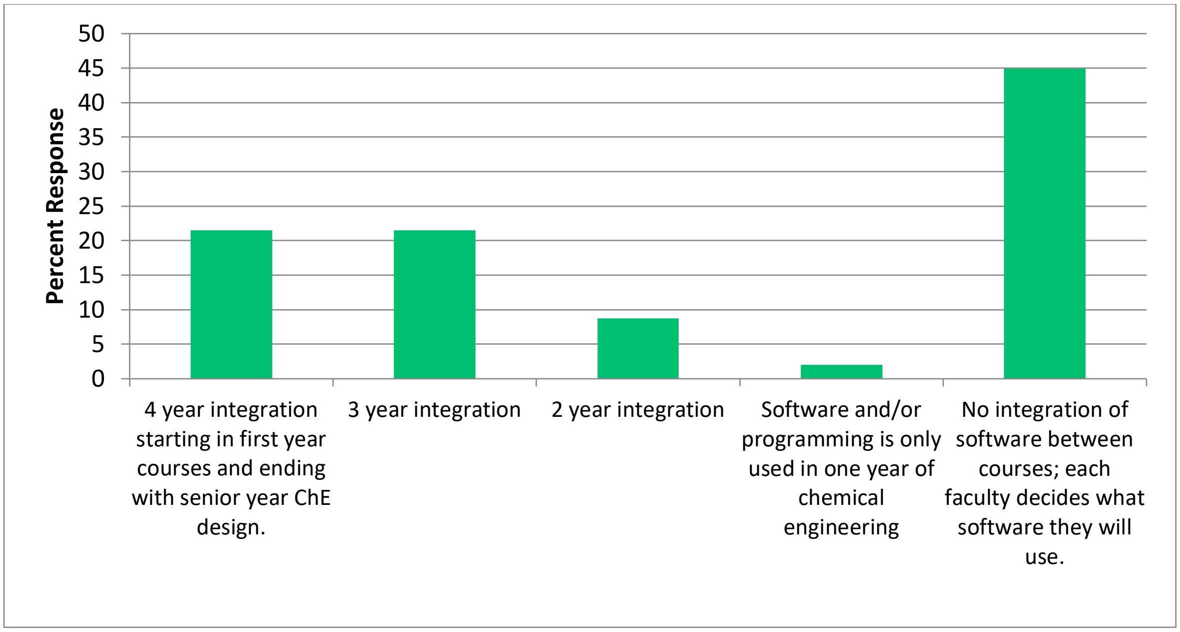

Figure 7: Responses to "Does your department coordinate the use of computer software and/or programming across the curriculum? If so, which scenario do you follow? Please give an example of this integration in the comment field."

The Academic survey also asked a question on the integration of software and the number of years that it is integrated; the results are shown in Figure 7. Integrated teaching of software requires faculty to first agree on the software that will be used and then co-ordinate what software they are using as well as what is taught in a sequence of courses. This co-ordination can typically be done in semester review meetings, and it is best if it is coordinated with the support of the department chair. In addition, when someone new teaches a course, then this information must be passed on. Integration of software in courses is labor intensive, and that is probably why 45% of departments have no formal integration of software. Of the departments that have integration 21% have 4 years of integration, 21% have 3 years, and 9% have 2 years. Integration of software between classes minimizes the time students devote to learning new software and allows them to become advanced users of the software. From another survey question just over half of faculty believe that graduates are well prepared to use computer software and programming to solve engineering problems. Perhaps one of the reasons for this low performance is the lack of integration of the software at many universities.
Another possible reason for the low integration of software use is the perceived barriers for its use by faculty. In response to the question on what are the barriers for faculty not using computer aids, the most common response was that faculty were not trained in these computer tools and additionally faculty do not have the time that is required to learn how to use these tools. Many faculty did not use these software programs as undergraduates and currently do not use the software in their research, so there is little incentive to learn the programs. There are several tools/books that have been prepared for students to learn software such as process simulators [6, 7]. If faculty used these materials as well, then the amount of use of this software could increase in the lower level courses.

Another survey question was asked to determine what methods were used to introduce students to computational software. Software companies have tutorials for their software and update these for each version, but these are not optimal for use by students. Instead as seen Table 1, most faculty prepare their own tutorials. Preparing tutorials is a large sink in time for faculty. A major amount of effort must be devoted in making the original tutorial and then updating these tutorials to match new versions of the software. This is an issue that needs to be addressed. In response to a survey question, there is a demand for tutorials for student use in courses. Aspen has tried to address this by preparing tutorials, AspenPlus Teaching Modules, through their university program [8].

Table 1: Responses to "What method do you use to introduce students to the computational software that you use in your classes? (select the main method used by students)"

Answer Choices	Responses	
Examples of how to use the software are given in the textbook used for this class.	13%	20
I prepare tutorials for the students on how to use the software.	70%	106
I use tutorials prepared by the software vendor.	2%	3
I use tutorials that are prepared by other instructors but not formally published in a textbook or internet collection.	5.3%	8
I do not give any formal instruction or tutorials to the students and expect them to learn this on their own.	6%	9
Other methods (please specify)	3.3%	5
	Answered	151

There is a growing trend at universities to eliminate computer rooms. This is now possible because many universities require engineering students to have their own laptops and most software can run using servers (cloud). Table 2 illustrates how universities are delivering software to students. At present there is a mix between computer labs and providing students software to load on their computers. The lowest method of delivery is requiring students to purchase the software, at 20%. Certain vendors allow the software to be run on the CPU of the laptop by providing a license that can be borrowed for a limited time by students. For example Aspen Plus and COMSOL both have this ability. Other vendors give a site license for any student or faculty at the college/university to download the software to their computer and run on their CPU. MATLAB is a good example of a vendor that permits this method of use. Software that is only developed for one operating system like Aspen Plus and POLYMATH can be used by any operating system by using cloud software. From this survey about half of the universities have this method of delivery.

Table 2: Select the method of delivery of chemical engineering software to your students. (Select all that apply)

Answer Choices	Responses	
Students purchase software and run it on their personal computers.	20%	31
Students download the software to their personal computers and the university provides licenses for students to run software on their personal computers	69%	105
The university provides chemical engineering software through a cloud service that runs on a virtual machine. (Citrix etc.)	48%	73
Chemical engineering software is available in campus computer laboratories.	74%	112
Other (please specify)	7%	11
	Answered	152
	Skipped	2

How do professors assess student's ability to use computational tools? As seen in Table 3 the majority of professors only require students to use computational tools for homework and do not test them (46%). The professors that test students on their computational ability do so using a computer room, individual laptops or desktops, or have them answer questions about the software on a written exam. This survey did not ask a question on the use of calculators vs. computers on exams but based on current practice we can assume that 100% of professors require calculators on exams. It is expected on future exams that the amount of testing using computational tools will grow to the point where laptop computers will be required instead of calculators.

Table 3: Responses to "Do you give in-class exams in which students are required to solve problems using chemical engineering software? If so select the method that you use."

Answer Choices	Responses	
I do not test individual students on their computer usage	46%	70
I give exams in which students solve problems using engineering software in a computer room.	22%	34
I give take home exams in which students are required to use chemical engineering software either on their personal computers or in a computer room.	21%	32
I test students on their computer skills by asking appropriate questions about using the software, but do not allow them to use the computer during the exam. (e.g. they give the POLYMATH or MATLAB code or give the steps to use the process simulator).	19%	29
I give exams in which students are required to use chemical engineering software on their personal computers in the classroom.	16%	25
Other (please specify)	7%	10
	Answered	152
	Skipped	2

Finally, this survey did an extensive analysis of what software was used in each course of chemical engineering (Question 4). As shown in the industrial survey a large majority of students are required to use spreadsheets in all classes. MATLAB is the next popular software with its highest use in a Numerical Methods class and in Process Dynamics and Control courses (both 71%). In Chemical Reaction Engineering/Kinetics courses both MATLAB and POLYMATH are used. As expected the class that has the major use of Process Simulators is Chemical Process Design (95%) which was similar to the 2001 survey in which 94% used process simulation in Design. For the current survey the Separations/Mass Transfer course had the next highest use of simulators (65%) and then Thermodynamics (49%). For the 2001 survey process simulators were used in the majority of Separations courses (57%) and (36%) in the Thermodynamics courses. This shows a growth in the use of process simulators in these courses. Programming languages are used most in Computing/Numerical Methods (34%) and less than 20% in all other courses. This may be a result in the drop in the amount of programming required in chemical engineering courses from the 2001 survey, in which 45% of ChE departments stated that programming languages were required in subsequent ChE courses. Computational Fluid Dynamics is not being used to its full potential with a 33% use in fluids and 18% in Heat Transfer courses.

Table 4: Responses to "Select which software is used in your course assignments for the following chemical engineering classes. (multiple selections allowed) Please add any classes not listed in this table in the "Other" field. You only need to specify courses that you teach." (Percents are based on the total responses for a particular course. E.g. Spreadsheets in First Year Engineering 79/87=0.91

	Spreadsheets		MATLAB		POLYMATH		Process Simulator		Programming language		Data acquisition software		Computational fluid dynamics software		Total
First Year Engineering	91%	79	49%	43	3%	3	6%	5	20%	17	2%	2	1%	1	87
Principles of Chemical Processes or Stoichiometry	86%	83	27%	26	2%	2	18%	17	6%	6	0%	0	0%	0	96
Computing/Numerical Methods	49%	46	71%	66	8%	7	23%	21	34%	32	0%	0	6%	6	93
Fluids	65%	43	32%	21	5%	3	14%	9	8%	5	0%	0	33%	22	66
Thermodynamics	74%	58	38%	30	3%	2	49%	38	12%	9	0%	0	1%	1	78
Heat Transfer	72%	48	37%	25	3%	2	18%	12	6%	4	1%	1	18%	12	67
Separations/Mass Transfer	70%	64	28%	26	7%	6	65%	60	8%	7	0%	0	2%	2	92
Materials	88%	28	16%	5	0%	0	3%	1	9%	3	3%	1	0%	0	32
Chemical Reaction Engineering/Kinetics	53%	52	52%	51	48%	48	24%	24	12%	12	0%	0	2%	2	99
Chemical Process Design	64%	64	24%	24	5%	5	95%	95	5%	5	0%	0	1%	1	100
Unit Operations Laboratory	85%	66	33%	26	4%	3	33%	26	13%	10	38%	30	3%	2	78
Process Dynamics and Control	31%	26	71%	59	7%	6	23%	19	20%	17	12%	10	0%	0	83
Other course not given above: (please specify course name below)	35%	8	9%	2	9%	2	30%	7	30%	7	0%	0	22%	5	23
Other Course marked above (please specify course name)															24
													Answered		152
													Skipped		2

Conclusions

This survey has found that chemical engineers use computer software applications in their work, while computer programming in industry is not a major task by chemical engineers. Spreadsheets are major tools used by chemical engineers in industry, and the use of statistical software has increased in use over the past 20 years. The emergence of Python as a programming tool is a key change from 2003. Machine learning and data analytics is an area that is expected to grow in the future, and chemical engineering educators need to evaluate the effectiveness of our teaching on these subjects. The effective use of Python and data analytics are emerging opportunities in education, as are software tutorials that faculty, students, and industry could use.

References

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