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An International Exploration of Electrical and Computer Engineering Education Practices

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Professor Euan Lindsay is a Mechatronic engineer, a discipline that integrates computers, electronics and physical hardware. Prof Lindsay's PhD investigated whether remote and simulated access alternatives to the traditional in-person laboratory experience could provide the same learning outcomes for students.

Prof Lindsay's work in Remote and Virtual laboratory classes has shown that there are significant differences not only in students' learning outcomes but also in their perceptions of these outcomes, when they are exposed to the different access modes. These differences have powerful implications for the design of remote and virtual laboratory classes in the future, and also provide an opportunity to match alternative access modes to the intended learning outcomes that they enhance.

Prof Lindsay is the Foundation Professor of Engineering at Charles Sturt University. His research interests include engineering education, telecontrol (particularly internet-based telecontrol), artificial neural networks, and rehabilitative technologies for people with sensing impairments.

Prof Lindsay was the 2010 President of the Australasian Association for Engineering Education. He is a Fellow of Engineers Australia, and a Fellow of the UK Higher Education Academy. Prof Lindsay was the recipient of a 2007 Carrick Award for Australian University Teaching. In 2005 he was named as one of the 30 Most Inspirational Young Engineers in Australia.

An International Exploration of Electrical and Computer Engineering Education Practices

Abstract

This research paper describes results from an international survey of electrical and computer (ECE) educators and stakeholders about the current state and future directions of ECE education. Technological, economic, and social pressures are reshaping higher education, but there is little consensus about the future. IEEE created a Curricula and Pedagogy Committee (CPC) and charged it with forecasting the future of ECE education and to make recommendations regarding roles that IEEE will play in preparing for and crafting that future. To gather more information from members of the engineering education community, the committee conducted a global survey. Surveys were deployed in 2014 to those who (1) teach undergraduate students, (2) administer a degree program (i.e., Department Chairs), (3) serve as a top-level administrator over all engineering degree programs (i.e., Deans), and (4) work professionally in engineering. Survey items address areas including instructional strategies, instructional technologies, assessment strategies, curricula, evaluation of teaching, and preparation of graduates. With over 2100 respondents, these survey results can inform conversations about the future of ECE education. This paper focuses on responses from the over 600 academic respondents. When asked about teaching and assessing problem solving, moral/ethical reasoning, and design, respondents were most likely to teach problem solving and design. This suggests that ethics may not be getting the attention that is needed. Lecture was the most popular teaching practice employed for these three topics. Locally developed tests and instruments were used most often for assessing problem solving, design, and moral/ethical reasoning. Emphases on co-op, industry partnership, and internships tended to be relatively uniform in ranging from significant to almost none. Almost all engineering programs are presently accredited or expected to be accredited within five years. Evaluating teaching was done primarily using student evaluations but peer evaluations, self-evaluations, and administrator evaluations were also commonly used.

Introduction

Technological, economic, and social changes will reshape undergraduate engineering education. Anticipating and acting on future developments would enable engineering programs to prepare, but there is little consensus on its future in 10 years. IEEE created a Curricula and Pedagogy committee (CPC) and charged it to forecast the future of ECE education and to make recommendations regarding roles that IEEE will play in preparing for and crafting that future. As an initial step, the committee engaged in a scenario planning exercise[1,2,3,4] to consider possible trends in engineering education. Then, the committee developed and administered a survey to confirm and revise trends that emerged from scenario planning. With over 2100 respondents, these survey results can inform conversations about the future of ECE education. Results of the scenario planning exercise and the design and administration of the survey are described in detail elsewhere.[5, 6]

Results were presented previously describing current and expected future teaching methods and curriculum approaches as well as the prevalence and acceptance of online courses and Massive Open Online Courses (MOOCs) and different teaching resources.[5] Regarding teaching methods, it is not surprising that lectures were by far the most likely educational practice used currently and expected to be used in the next five years. However, 4% of respondents indicated that they never plan to lecture again. Laboratories were also likely to be used often. The only other practices that a majority of respondents indicated will be responses used at least once per week were "having individual students conduct activities beyond listening and taking notes" and "having individual students do homework to prepare for class." Strategies using teams were more likely to be projects and were expected to be used less often. Service learning and distance education were the least likely to be used. In general, results were consistent with those of Borrego, Froyd, and Hall,[7] which surveyed engineering department chairs in the United States about adoption of seven innovations in engineering education. Many more respondents expect to use distance education, MOOCs, undergraduate research, service learning, and work placements in the next 5 years than they did during their previous semester. However, lecture and laboratories will still be used more frequently.

Respondents currently use or expect to use several electronic resources in the next five years; electronic notes, course management systems, online tutorials, downloadable software, eBooks, and virtual and simulated laboratories were the most frequently selected items for future use. However, most online collaborative or social resources scored low. This suggests that the most popular uses of technology are those that simulate the most familiar (albeit passive) approaches to learning.

Respondents were much more likely to teach courses in-person than online. Administrators appear to be adapting to the availability of curricular resources. The majority of administrators were likely to encourage the use of teaching materials developed by another academic institution (51%). About 80% of respondents are at institutions that have not yet begun awarding credit for student participation in MOOCs. Respondents believe that their institution is more likely to award credit for MOOCs in the future with about half expecting their institution to award credit within 15 years and half believing it to be unlikely.

In this paper, we present additional results relating to teaching and assessing problem solving, moral/ethical reasoning, and design, as well as overall curriculum, assessing teaching quality, and accreditation.

Methods

Surveys were deployed in July-August 2014 to individuals throughout the world who (1) teach undergraduate students, (2) administer a degree program (i.e., Department Heads or Chairs), (3) serve as a top-level administrator over all engineering degree programs (i.e., Deans), and (4) work professionally in engineering. Invitees were a stratified random sample of IEEE members and the Electrical College of Engineers Australia, along with a convenience sample of other engineering educators as described in Ohland et al.[5] Survey items address areas including instructional strategies, instructional technologies, assessment strategies, curricula, evaluation of teaching, and preparation of graduates. This paper focuses on responses from the over 600 academic respondents. Of the academic respondents, 17% of the faculty members were women, 11% of the Department Heads, and 10% of the Deans.

Information about departments was obtained using responses from department heads. Forty percent (40%) of the Department Heads indicated that their departments enrolled 200 or fewer undergraduates. Undergraduate enrollment in another 40% of the departments was between 201 and 500, and about 20% had more than 500. Department Heads provided information on size of their faculty; 9 or fewer people who teach – 15%; between 10 and 20 – 36%; between 21 and 29 – 18%; and larger than 30, 31%. They indicated the average workload for faculty members was 47% teaching, 34% research, 15% service, 11% partnership, and 7% other.

Department Heads reported that the primarily undergraduate-focused institutions were similarly divided between comprehensive institutions (25%) and technically focused institutions (17%). Combining responses from Department Heads and Deans, the majority of administrators (55%) indicated that their institution was research-focused, some in many fields (42%), some in only technical fields (13%). More details about all survey respondents are described elsewhere.[5]

Teaching and Assessing Problem Solving, Moral/Ethical Reasoning, and Design
To understand contextual variation in approaches to teaching, respondents were asked to describe how they teach and assess three student outcomes that are prominent in accreditation—problem solving, design, and moral and ethical reasoning. Their responses are collated in Tables 1 and 2.

Invalid responses are ones where respondents reached this point in the survey but did not select any choice for the area (problem solving, design, or moral/ethical reasoning) including "did not" teach or assess.

Table 1 – Approaches to Teaching

	Problem Solving	Design	Moral / Ethical Reasoning
Lecture (live or recorded)	85%	67%	49%
Assign students individual exercises in class and provide feedback in class	63%	39%	19%
Textbook problems as homework	67%	35%	9%
Assign team exercises in class and provide feedback in class	47%	35%	16%
Problem/project-based learning in courses prior to capstone projects	42%	44%	12%
Entire course devoted to this subject	36%	30%	12%
Capstone design projects	21%	40%	10%
I did not teach this	2%	6%	36%
Invalid responses	28	70	151

For all three domains, lecturing remains the dominant form of instruction, with its dominance strongest in the Moral and Ethical Reasoning domain. Instructors use a wider range of approaches to teach Problem Solving and Design than they do for Moral and Ethical reasoning, with respondents selecting more approaches on average for these domains.

Instructors reported being more likely to use individual exercises in class than team-based exercises, with this preference strongest in Problem Solving, where textbook problems are also a common technique.

Table 2 – Approaches to Assessment

	Problem Solving	Design	Moral / Ethical Reasoning
Locally developed tests / instruments	75%	48%	27%
Instructor judgment to evaluate student projects in courses prior to their capstone courses	36%	36%	17%
Locally developed rubrics to evaluate student projects in courses prior to their capstone courses	33%	30%	16%
Instructor judgment to evaluate student capstone projects	26%	30%	23%
Locally developed rubrics to evaluate student capstone projects	23%	24%	14%
Published tests / instruments developed by others	31%	16%	10%
Concept inventories	19%	12%	8%
Externally evaluated by experts from industry	12%	11%	8%
I did not assess this	4%	8%	48%
Invalid responses	37	39	213

A clear theme for local assessment emerges from the responses, with locally developed tests being the most common assessment approach in all three domains. For assessment, instructor judgment is marginally preferred to locally developed rubrics in all domains, both at the capstone and pre-capstone level. External evaluation, whether directly through industry experts or indirectly through concept inventories and published tests, comprised the set of least preferred assessment methods.

Again there was a wider reported range of assessment approaches for the Problem Solving and Design domains than for the Moral/Ethnical Reasoning domain, with respondents indicating on average a larger number of approaches in use.

It is significant to note that 48% of respondents indicated that they did not assess moral and ethical reasoning. While a potentially disturbing figure, when considered in light of Table 1's statistic of 36% not teaching this outcome, it is less of a concern. This does raise the issue, however, of what proportion of respondents are not teaching, or not assessing (or both) each of the three outcomes.

Table 3 shows how the percentage of respondents who taught and assessed, taught but did not assess, did not teach but did assess, and did not teach or assess for problem solving, design, and moral/ethical reasoning. For problem solving and design, most respondents teach and assess it with very small percentages in the other areas. Given that problem solving is considered an essential part of engineering, it is good that 95% of instructors are teaching and assessing this. Design is also integral to engineering and was almost as commonly taught and assessed (90%). Despite being an important aspect of engineering practice, moral/ethical reasoning appears to have a different story. Half of the instructors reported teaching and assessing this which is heartening since this is not just capstone classes. This suggests that instructors are sharing some of the responsibility for teaching this important outcome that is often featured in accreditation. However, teaching and/or assessing ethics is far less commonly addressed in engineering curricula than either problem solving or design. Note than 38% of the survey respondents neither teach nor assess this outcome.

Table 3 – Percentage of respondents who taught and/or assessed problem solving, design, and moral/ethical reasoning.

	Problem Solving (N=417)	Design (N=384)	Moral/Ethical Reasoning (N=236)
Taught and assessed	95%	90%	50%
Taught but did not assess	4%	4%	11%
Did not teach but did assess	1%	2%	1%
Did not teach and did not assess	1%	4%	38%

Note: Numbers in the Problem Solving column do not add to 100% due to rounding.

Responses as to Which Courses are Taught

Respondents were asked to state a specific course that they taught in the previous academic term and use that when answering the questions about problem solving, moral/ethical reasoning, and design. Respondents chose courses that span the undergraduate curriculum with 22% choosing first year, 34% second year, 44% third year, 34% fourth year, and the rest fifth year or higher. 37 respondents listed more than one course and were not included in further analysis. The single course responses were coded using common categories, and the most common responses – the functional "core curriculum" of Electrical and Computer Engineering – is shown in Table 4.

Table 4 – Codes for Courses Listed

Course	Number of Responses
Programming	30
Circuits	28
Digital Electronics	27
Analog Electronics	27
Controls	21
Computer Architecture	19
Power	18
Introduction	16
Capstone	13
Communications	13
Math/Science	13
Networks	13
Database	12
Electricity and Magnetism	12
Signal Processing	10

Table 4 has been filtered to only include courses for which there were 10 or more responses; as such it only accounts for 272, or less than a third, of the total responses to the question. This "long tail" of responses illustrates the diversity of course offerings in the discipline of Electrical and Computer Engineering. The potential for this tail to grow even longer raises significant opportunities for specialization in the future, as well as potential challenges for maintaining a clear core curriculum in the future.

Responses about Curriculum Overall

Department heads and Deans were asked several questions about overall curriculum. Administrators were asked to describe whether their current engineering curriculum emphasized theory or engineering practice. To clarify practice, the survey item was "Curriculum emphasizes extensive engineering practice (for example, multiple required co-operative learning experiences or internships, majority of courses emphasize problem/project-based learning, students take courses emphasizing engineering design throughout the entire engineering curriculum, other examples can be included)". Responses are shown in Table 5. Department Heads were evenly split between these two choices, while Deans showed a small preference for engineering practice. Some respondents chose "Other". For Deans, 5 of these 8 responses were "In Between" and 1 was "Both". For Department Heads, 6 of the 22 responses were "In Between", 9 described a theory-based curriculum with lots of laboratories, and 2 said "Both".

Table 5 – Which best describes your current engineering curriculum?

	Dept. Head (N=161)	Dean (N=62)
Curriculum emphasizes theory-based courses; students apply what they learn in one or two design courses	43%	40%
Curriculum emphasizes extensive engineering practice	43%	47%
Other	14%	13%
TOTAL	100%	100%

Administrators were also asked about the level of emphasis that their curriculum places on learning experiences linked to engineering practice. Tables 6, 7, and 8 show the responses for Co-op, Industry partnerships, and Internships. Choices ranged from very little emphasis to a strong emphasis or "do not know". The small number of "do not know" responses are excluded.

Table 6 shows that Department Heads and Deans responded similarly showing that most programs have little emphasis on co-op, that is alternating school and work learning experiences. Only about 10% of respondents had a strong emphasis on co-op.

Table 6 – How much emphasis does your engineering curriculum place on alternating school and work experiences (co-op)?

		Dept. Head (N=154)	Dean (N=57)
very little emphasis	1	33%	35%
	2	19%	16%
	3	23%	21%
	4	14%	18%
a strong emphasis	5	10%	11%

Table 7 shows that Deans reported that their programs had greater emphasis on partnerships with industry than Department Heads did. About a third of each group responded with the neutral category. Thirty-six percent (36%) of Deans chose the stronger emphasis categories (4 & 5) while only 17% of Department Heads did. This is reversed for the lesser emphasis categories (1 & 2) where 33% of Deans but 55% of Department Heads chose this. Because Deans often have a larger role on fundraising and building relationships with external organizations than Department Heads, Deans may be more aware of partnerships that the college has with industry.

Table 7 – How much emphasis does your engineering curriculum place on industry partnerships in the classroom?

		Dept. Head (N=155)	Dean (N=58)
very little emphasis	1	24%	14%
	2	31%	19%
	3	28%	31%
	4	12%	19%
a strong emphasis	5	5%	17%

Similar to industry partnerships, Table 8 shows that Deans reported that their programs had greater emphasis on internships than Department Heads did. The differences, however, are smaller. About a third of each group again responded with the neutral category. 28% of Deans chose the strongest emphasis (5) while only 19% of Department Heads did. This is reversed for the least emphasis categories (1&2) where 15% of Deans but 26% of Department Heads chose this.

Table 8 – How much emphasis does your engineering curriculum place on internships?

		Dept. Head (N=159)	Dean (N=60)
very little emphasis	1	8%	5%
	2	18%	10%
	3	30%	32%
	4	25%	25%
a strong emphasis	5	19%	28%

Administrators responded to a question about in which year(s) students study design. Responses are shown in Table 9, noting that respondents were free to select multiple years if applicable.

Table 9 – In which year(s) do undergraduate students study design?

Year	Dept. Head (N=166)	Dean (N=64)
1	36%	36%
2	51%	48%
3	71%	59%
4	72%	67%
5 or higher	16%	20%

The results show that the likelihood that students will be studying design increases as they progress through the curriculum since the highest percentage of respondents indicated it is included in the fourth year, closely followed by the third year. The emphasis in the fourth year is consistent with the prevalence of capstone design classes.[8] Given the emphasis on first year engineering programs in the U.S.,[9,10] it is surprising that only about a third of respondents said that students study design in the first year.

Responses were similar for both Department Heads and Deans; however it is worth noting the difference between their perceptions and those of the faculty who teach (Table 1), where 94% of all respondents indicated that they taught design in their courses.

Responses about assessing teaching quality
Administrators were asked how they will assess teaching quality in the next 5 years. Responses are shown in Table 10. Note that participants could select all that apply or "other".

Table 10 – How will your department, college, or school evaluate teaching quality in the next 5 years?

	Dept. Head (N=162)	Dean (N = 63)
Student Evaluations	85%	84%
Peer Evaluations	64%	75%
Self-Evaluations	63%	65%
Administrator Evaluations	56%	62%
Other	17%	8%

Student course evaluations are by far the most reported assessment with around 85% of each group choosing this. This is consistent with literature showing that course evaluations are commonly used.[11,12,13]

Peer, self, and administrator evaluations follow in that order. For Department Heads, 17 of the 27 "other" responses referred to an accreditation body and 5 referred to an external evaluator with many from industry. The Deans who chose "other" listed ASEE workshops, international bodies, learning assessments, national evaluations, and success in subsequent classes.

It is worth noting that while student responses are the dominant form of evaluation, they are most commonly used with some form of triangulation – only 2 out of 53 Deans and 12 of 137 Department heads who indicated that they would use student evaluations of teaching did not also indicate another form of evaluation.

Responses about Accreditation
Accreditation was explored through several questions. Most administrators (90%) reported that their programs were accredited. Of those who were not, most said they planned on seeking accreditation in the next 5 years. Responses are shown in Tables 11 (by numbers of respondents) and Table 12 (by percentages). If they responded that they were accredited, respondents were asked to list the specific accrediting agency. The most common agency listed was ABET (88 out of 187 responses), followed by other national agencies such as

Engineers Australia, CEAB (Canadian Engineering Accreditation Board), or Accreditation Commission of the Czech Republic. Respondents were given the option to list more than one accrediting agency and 18 respondents did. Three listed regional accreditation bodies such as SAC (Southern Association of Schools and Colleges) in the U.S.A. One listed ABET with SAC as the first agency and another IEEE which is a professional society that participates in ABET, but does not accredit engineering programs.

Table 11 – Are the programs at your institution accredited? If not, is your institution planning to seek accreditation for any of your programs in the next 5 years?

	Accredited		Seeking accreditation in next 5 years?		
	yes	no	yes	no	don't know
Department Head	147	14	10	1	3
Dean	54	8	7	0	1
TOTAL	201	22	17	1	4

Table 12 – Are the programs at your institution accredited? If not, is your institution planning to seek accreditation for any of your programs in the next 5 years?

	Accredited		Seeking accreditation in next 5 years?		
	yes	no	yes	no	don't know
Department Head (N=161)	91%	9%	71%	7%	21%
Dean (N = 62)	87%	13%	88%	0%	13%

Conclusions

The survey responses show that the archetypal model of instructor-centric teaching is still prevalent, but that other approaches are being used. Lecturing is still the dominant form of instruction; instructor judgment is preferred to rubric-based assessment, and both are far preferred to assessment instruments developed elsewhere. This model is most strongly represented in the teaching of Design and Problem Solving, with the teaching of Moral and Ethical Reasoning more likely to use different approaches, but for instructors to rely upon fewer approaches as they do so.

It is noteworthy that only 50% of instructors responded that they taught Moral and Ethical Reasoning, whereas teaching of Problem Solving and of Design was near ubiquitous. There was also some misalignment between teaching and assessing these domains, with 5-10% of respondents indicating that they either taught but did not assess, or they assessed but did not teach, that particular domain. The responses do not provide sufficient information to determine if this misalignment is a deliberate pedagogical choice (e.g., assessing, but not re-teaching, material that should have been learned in pre-requisites) or simply poor practice.

Emphases on co-op, industry partnership, and internships vary substantially between institutions, however the distributions were perceived similarly by Department Heads and by Deans. Almost all engineering programs are presently accredited or expected to be accredited within five years.

The commonly perceived primacy of student evaluations in evaluating teaching was reinforced by the responses of administrators, but it is clear that this is by no means the only form of evaluation that is used. Peer evaluations, self-evaluations, and administrator evaluations were all reported as common, with many respondents indicating three or more forms of evaluation were in use.

It is clear that there is a wide range of courses taught in the discipline of Electrical Engineering; this survey has provided some insight into the wide variety of ways in which these courses are taught, valued and evaluated.

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