GAUGING THE IMPACT OF CDIO AND MOMENTUM FOR FURTHER CHANGE

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ABSTRACT

Recently, within the CDIO community, there has been a focus on the impact of CDIO and an emphasis on how engineering education will change in the future due to the rapidly changing technological world (Industry 4.0). This paper focuses on the results of a new alumni survey, based on an original survey at the authors' School in 2004, but with the objective of understanding the subsequent impact of 12 years of CDIO graduates and also benchmarking and determining if there is obvious momentum for future curriculum change. Specific areas that are discussed include:

- A comparison with the previous alumni survey to understand key syllabus topics (i.e., programme learning outcomes and their hierarchy).
- What has changed after 12 years of CDIO graduates?
- A reflection on 15 years of CDIO implementation.
- The engineer of the future – are there any obvious influences on engineering education in 9-10 years (2030)?

Overall, it appears that CDIO curriculum implementation in the School over the past ten years has been accompanied by an increase in the skill levels of graduates in several key areas. Further work will be carried out to assess the suitability of current programmes for the expected technological and societal needs of stakeholders moving into the next 10 years and beyond.

KEYWORDS

CDIO, graduate skills, survey, curriculum design, Standards: 1-12

INTRODUCTION

The School of Mechanical and Aerospace Engineering at Queen's University Belfast has been a collaborator in CDIO since 2003 and has an ongoing change management plan for curriculum reform based on the CDIO principles and methodology. In 2004 the School developed and implemented a new degree programme based entirely on this ethos and has been progressively feeding this pedagogy and experience back into its other degree programmes. In addition, it has been disseminating this best practice internally within its university and at regional and international CDIO events in subsequent years. The School has therefore gained experience in key pedagogical areas such as curriculum change management, workspace design, active and interactive learning, introductory courses, mathematics provision for engineers, peer assessment and review, project and problem-based learning, and the collaborative quality enhancement of programmes. The School is now keen to evaluate the impact of CDIO. In 2004, the School carried out an alumni survey, which is presented in Chapter 3 of the CDIO book (Crawley E.F., Malmqvist J., 2007) as part of a bigger project to ratify and define the CDIO Syllabus. Since then, other CDIO collaborators have used such alumni surveys to not only benchmark their engineering curricula, but also to check proficiency levels against the CDIO syllabus and gauge effects on educational quality.

The aim of university engineering programmes should be to equip graduates with the technical, personal, and professional skills required to meet the ever-evolving needs of industry. As we move into the fourth industrial revolution, "Industry 4.0", paradigm shifts are expected in the way that we work, live and interact with others, driven in particular by rapid technological advances (Marr, 2018). Kamp (2020) refers to Industry 4.0 evolving into "Society 5.0" and states *"Every system, product or service, including higher education, will have aspects or parts that are dramatically enhanced or disrupted by digital technologies. Anything that can be automated, will be. Routine tasks are becoming increasingly automated, while newly created jobs require different competencies."* Additionally, the global crisis caused by the Covid-19 pandemic may have significant and lasting influence on the way in which industry operates. This has brought about obvious challenges but may also serve as a catalyst for change and a driver for the introduction of disruptive technologies. It is therefore unlikely that the way in which industry operates will return to the pre-pandemic status quo.

The CDIO engineering education model was designed to develop well-rounded graduate engineers who have appropriate skills for modern industry, and it is therefore important to reflect on whether the existing model continues to meet their needs in their professional lives and supports the needs of industry both now and into the future. This is particularly important at this time of rapid change. The importance of adapting curricula, and benchmarking programmes to achieve these aims has been previously reported on in many studies (Bankel et al., 2005; Cloutier et al., 2012; Crawley E.F., Malmqvist J., 2007; Lang et al., 1999; Malmqvist et al., 2005). Numerous papers have reported on how CDIO has been implemented in different institutions (Schrey-Niemenmaa et al., 2010; Sparsø et al., 2007). In addition, some studies have since reported on a review of the effect of CDIO curriculum implementation as measured by a variety of indicators (Edvardsson Stiwne & Jungert, 2010; Huiting, 2014; Malmqvist et al., 2015)

Feedback from alumni is one means of gaining valuable insights into current needs in industry (Mechefske et al., 2005) and can shed light on the continuing relevance, or otherwise, of aspects of curricula, including identifying gaps in provision and allowing for future planning. In 2004, a series of studies were carried out to assess the extent to which individual engineering programmes met the needs of the CDIO Syllabus, and then in turn to determine whether they were fit for purpose as seen through the experience of alumni who were working as engineers in industry. Stakeholder surveys were carried out to assess the personal, professional, interpersonal and product, process and system building skills expected of graduate engineers, as well as opinions on the importance of aspects of the curriculum. The results of these surveys were presented in the CDIO book (Crawley E.F., Malmqvist J., 2007), and in individual papers by the universities involved (Armstrong et al., 2006; Armstrong & Niewoehner, 2008; Wyss et al., 2006). The specific programmes considered were as follows:

- Mechanical engineering at Chalmers University of Technology
- Mechanical and materials engineering at Queen's University, Kingston, Canada
- Applied physics and electrical engineering at Linköping University
- Aeronautics and astronautics at Massachusetts Institute of Technology (MIT)
- Mechanical and manufacturing engineering at Queen's University, Belfast (QUB)

The authors from the School of Mechanical and Aerospace Engineering at QUB decided that it was of interest to obtain an updated review of opinion about the experience of the degree programmes in the school to ensure that they continue to provide the skills and knowledge necessary for a career in the ever-evolving engineering industry. It was of particular interest to assess what effect, if any, has resulted from implementation of the CDIO-based syllabus within the school since the first graduates who completed a "full" CDIO programme completed their studies in 2010. Some previous follow-up surveys have been carried out by other institutions to assess the effect of the implementation of the CDIO syllabus, (Edvardsson Stiwne & Jungert, 2010; Malmqvist et al., 2010), but this study covers a longer time period since implementation, and also assess the effects of the past ten years of technological change. In addition, engineering programmes continually need to adapt to the wider technological and societal changes that take place, which are often reflected in accreditation requirements. For example, the UK Engineering Council's AHEP 4, which was published in 2020, calls for "***a sharper focus on inclusive design and innovation, and the coverage of areas such as sustainability and ethics. The coverage of equality, diversity and inclusion is also strengthened to reflect the importance of these matters to society as a whole and within the engineering profession*.**"(Engineering Council, 2020). There is also a clear need for increased focus on preparing graduates for a society in the shape of the UN's Sustainable Development Goals, and this will play a significant role in the new QUB strategic plan.

METHODOLOGY

For this work, the intention was to closely follow the work described above to acquire a more contemporary appreciation of stakeholder views to guide both the content and learning outcomes employed in the authors' programmes. In order to provide a direct comparison with the 2004 survey, an email survey was prepared with identical questions. An additional space was provided to allow respondents to provide free-form comments. A database of alumni from the School of Mechanical and Aerospace was obtained from the Alumni Office within the university. These included only those alumni who had consented to be contacted by the university for such purposes. The database was filtered to select only those who had graduated with relevant degrees, and to remove any alumni who had proceeded to subsequently qualify in other areas such as finance or law. The final pool contained 1002 contacts. The survey was sent on the 5th March 2020, just 2 weeks before the UK entered a national lockdown due to Covid-19. It was subsequently decided to send the survey out again to non-respondents in October 2020. The data received was analysed and compared with the data from 2004. In addition, the qualitative comments from alumni were considered.

RESULTS AND DISCUSSION

Number of Responses and Demographics

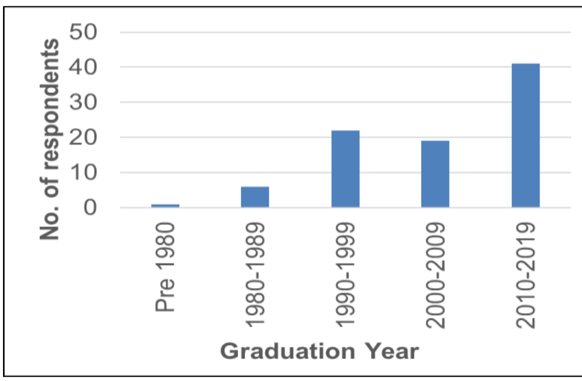
The initial survey that was sent in March was successfully delivered to 978 email addresses (97.6%) of contacts. The subsequent follow-up email was sent to those recipients who had no engagement with the original request. In total 89 responses were received from the survey. This was lower than expected but was most likely heavily impacted by the Covid-19 pandemic. This number compares with 143 responses from the original survey in 2004.

According to the data received, 17 of the alumni were female and 72 were male. This would be in line with the general graduate population from the School, where typically around 18-

20% of students are female. 57% of respondents graduated from Mechanical or Mechanical and Manufacturing degrees (Table 1), and most respondents graduated after 1990, (Figure 2). 85% of the respondents are currently located in Northern Ireland, the Republic of Ireland or Great Britain (Figure 3).

Table 1. Degree Programme Breakdown

Aeronautical Engineering	Aerospace Engineering	Manufacturing Engineering	Mechanical & Manufacturing Engineering	Mechanical Engineering	Product Design & Development
27%	13%	1%	11%	46%	1%



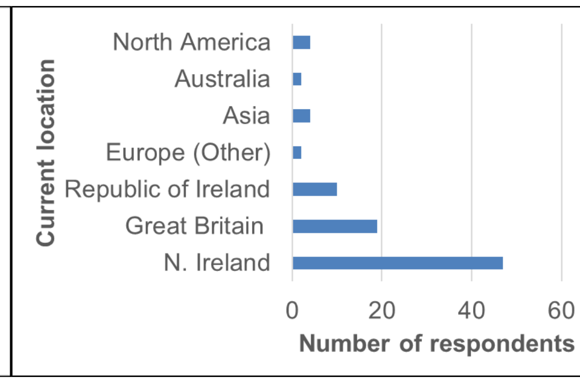


Figure 2. Respondents by graduation year Figure 3. Respondents by location

Ranking of Subject Importance

The survey asked alumni to rank the importance of having knowledge of several core mathematical and engineering science topics. The ranking of the importance of mathematical topics is shown in figure 4, indicating increases in the perceived importance of several topics between 2004 and 2020, with the clearest increases in the areas of transforms, complex numbers, calculus and vector calculus. This may be due to the increased need for expertise in areas such as computer programming and modelling. Slight decreases in the importance of traditional mathematical topics such as geometry, trigonometry and algebra are seen. For engineering science modules (Figure 5), alumni continue to place high importance on having a basic knowledge in the three main areas of Thermodynamics & Fluid Mechanics, Statics and Strength of Materials, and Engineering Dynamics, although this has fallen slightly between 2004 to 2020. There has been no notable change in the perceived importance of understanding the relationships, variables and parameters in the three main areas or in the importance of being able to write down and apply equations in calculations.

Topics additional to the core modules include those related to electrical and electronic engineering, production and manufacturing, and business and enterprise. The comparison of the perceived importance of these is shown in figure 6. Increases in perceived importance are apparent in the areas of electrical and electronic engineering, computer programming skills and related areas. This is not unexpected due to the rapid increase in the use of computer aided systems in manufacturing, production, and research and development, linked into the Industry 4.0 shift. Some small decreases are seen in the importance ranking of a variety of business and enterprise areas, while all other areas remain relatively unchanged.

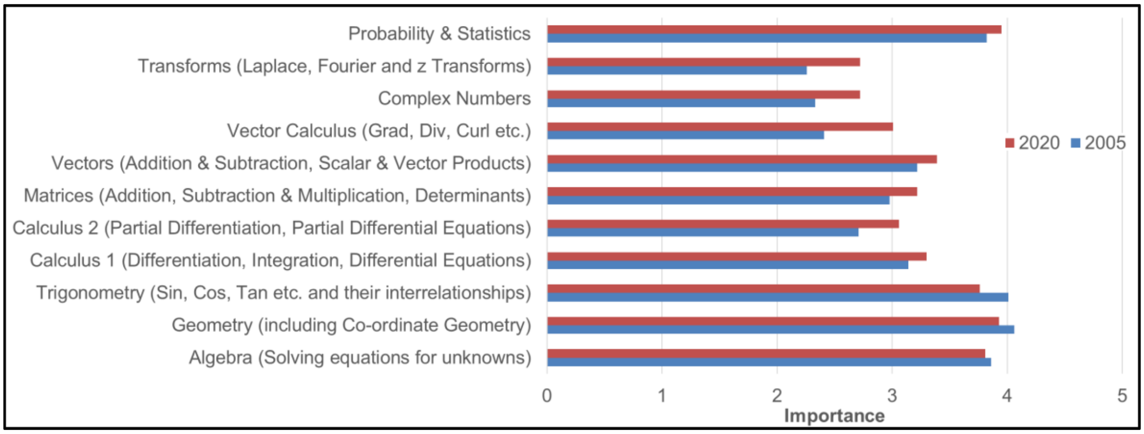


Figure 4: The importance of mathematical topics to alumni

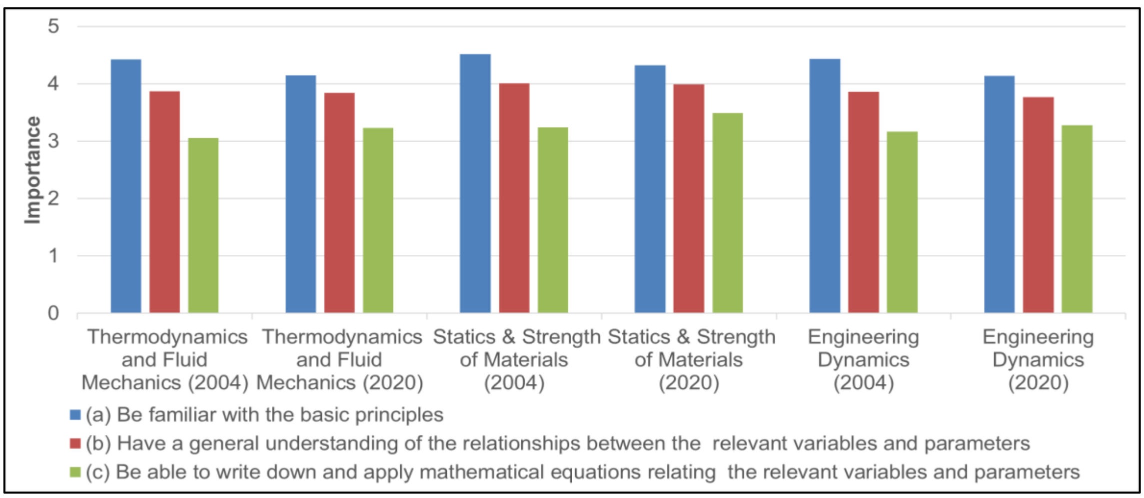


Figure 5: The importance of engineering science modules to alumni

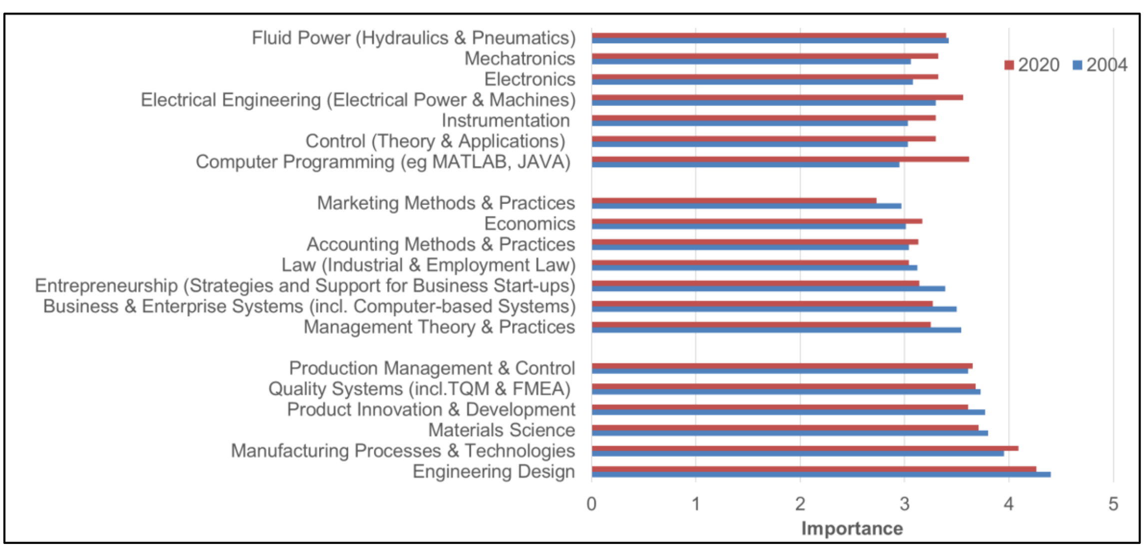


Figure 6: The importance of additional modules to alumni

Ranking of Skills

The results in figure 7 show the ranking of the importance placed by alumni on several graduate skills. When this data was presented in 2004 there was an adjustment of the data to fit with the ranking scale used by other institutions. Here we compare like-with-like with no scaling applied. In addition to the ranking of "importance", alumni were also asked to rate their own skills in these areas at graduation. The ratings of importance for both years are very similar for the majority of skills, but a modest but notable increase can be seen in all the Conceive-Design-Implement-Operate areas 4.3-4.6 from 2004 to 2020. Alumni ranked their own skills at graduation relatively low compared to their perceived importance of skills in all areas. The most closely matched perceived skill level relevant to the importance of the skill was in designing, followed by personal skills and attributes and communication skills. The biggest discrepancy in skill level relative to importance was in engineering reasoning and problem solving followed by the two key CDIO areas of Implementing and Operating.

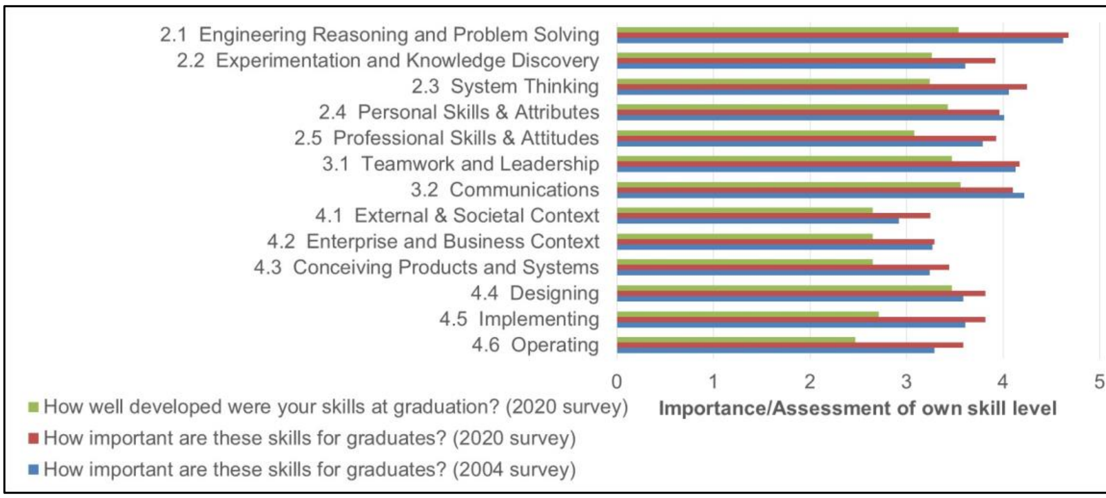


Figure 7: Ranking of the importance of skills, and perceived skill levels at graduation

The difference in perceived skills level between alumni who graduated after 2010, when the CDIO syllabus had been fully implemented was then compared with those alumni graduating before (Figure 8).

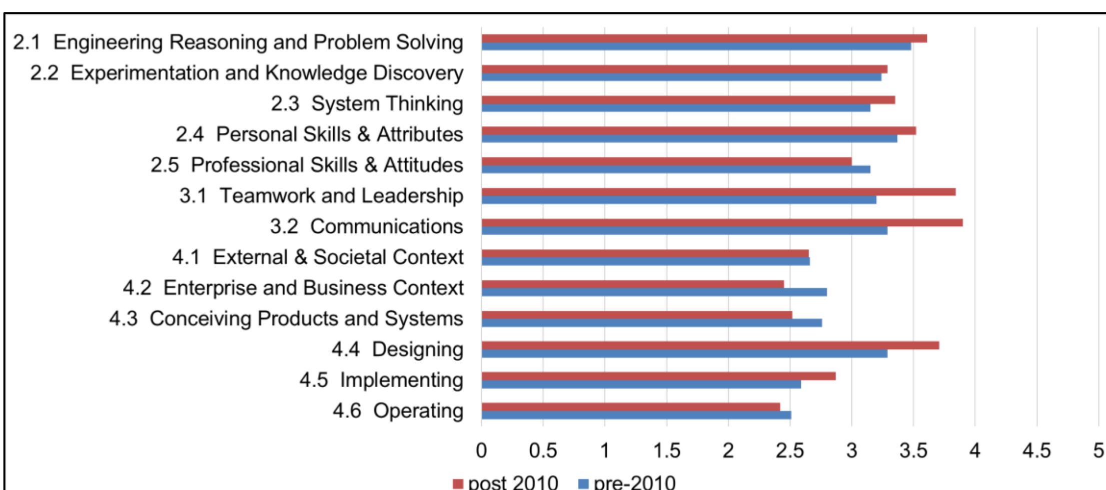


Figure 8: Perceived skill levels at graduation pre- and post-full CDIO syllabus implementation

Post 2010 graduates reported higher self-assessed skills in a few key areas, with the greatest improvement seen in teamwork and leadership and communication skills, this ties in with findings from two studies from Linköping and Chalmers (Edvardsson Stiwne & Jungert, 2010; Malmqvist et al., 2010). This was followed by improved design and implementation skills. Some decreases were seen in the areas of enterprise and business, and in conceiving products and services. Results suggest more work is needed in improving some key skill areas.

Comments by Alumni

Comments written by the respondents can be grouped into 5 main categories: Technology, Teamwork, Industrial experience, Professional Skills, and subject specific comments. The numbers of comments in these areas are presented in table 2. The comments have been grouped by whether the respondents had positive or negative comments about their experience in the area during their time at QUB, or if they commented that more time should be devoted to that area.

Table 2: Categories of Alumni Comments

	Positive comments	Negative comments	More required
Technology: Software, hardware, programming, electrical/electronic engineering	4		4
Teamwork: Group projects	2	2	
Industrial Experience: Placements, guest lectures, industrial visits, real-life examples	4		11
Professional skills: Business, enterprise, professional, soft skills	4		4
Subject specific needs	3		3

The area, which had the largest number of comments related to industrial experience, with respondents commenting positively on their industrial placement experiences. Alumni who graduated before the full implementation of CDIO also recommended more time should be devoted to developing students' experience in this area through a variety of means:

"I found my placement year particularly useful, and gained most of the skills that have helped me in my graduate job whilst on placement" (Post CDIO graduate)

"[industrial placements] were not the norm in queens at the time which I felt was a shame…both [placement] experiences were arguably the most important of my degree - more so than the actual courses I studied." (Pre-CDIO graduate)

"Real world problems should be further integrated within the course, such as guest lecturer from industry and attached team exercise. Visits to companies would also be very beneficial in the first few years, and encouragement of industrial placement." (Pre-CDIO graduate)

Comments relating to the use of technology reflected the increased importance placed by alumni on having knowledge in areas such as engineering software applications, computer programming, control systems and electrical and electronic engineering:

"Tools like MATLAB, Excel & VBA have proved useful. Going into a work environment where these wouldn't be commonplace I've been able to help streamline & improve many work processes" (Post-CDIO graduate)

"Emerging and existing high-tech manufacturing equipment would be a good area to cover. Robotic control, advancements in robotics, developments in significant manufacturing processes…" (Post-CDIO graduate)

Experience of teamwork during the degree programme was reported as both positive and negative, even by the same respondents:

"Teamwork is great, but I feel too much of the marks in these modules was based off of other people and they could really drag down your score." (Post-CDIO graduate)

Finally, there were various comments relating to the importance of developing a range of personal, professional and business skills in engineering graduates:

"there are a host of supplementary skills (project management, team leadership, management of risks & opportunities, communication & influencing, industrialization challenges etc.) which are critically important to becoming a good engineer in the "real world". It is these 'softer' skills which could have more attention." (Pre-CDIO graduate)

"Some are also fairly poor at the basics required in work, i.e., computer literacy and professional conduct via email etc.…the stereotype of engineers still holds firm, and many lack the basic skills to integrate into a team and use the communication channels well." (Post-CDIO graduate)

CONCLUSIONS

The results comparing alumni views between 2004 and 2020 on the importance of a various aspects of the engineering syllabus at QUB, and the attributes and skills required in industry has shown the following:

- The alumni showed a remarkably similar opinions on the importance of most of the core engineering subjects in 2004 and 2020, with greatest importance placed on familiarity with basic concepts, followed by understanding variables and parameters, and then by the ability to perform calculations.
- For mathematical topics, slightly more importance is placed on transforms, calculus and complex numbers in 2020 compared with 2004. Other mathematical topics hold similar importance or slightly lower.
- In the area of electronics, electrical engineering and computer programming there is a small uplift in the importance placed by the alumni in 2020 compared to 2004. This may be reflective of greater use of technology in their daily and professional lives as we move towards industry 4.0.
- The key professional, personal, and business context skills deemed important by alumni have remained surprisingly constant in a number of areas. However, we note some increase in the rating of importance of the Conceive-Design-Implement-Operate areas in the more recent survey.
- Alumni perceptions of their own skill levels are generally low compared to the importance they place on each area.
- Comparing alumni who graduated before and after the implementation of the CDIO syllabus shows increases in perceived skill level in the areas of teamwork and communication and in design skills, but further work needs to be done to improve other key skills in graduating students.

- The comments made by a number of respondents give an interesting insight from those in industry, highlighting the need to develop well-rounded engineers who are equipped for the world of work with up-to date technical skills supported by industrial acumen and appropriate professional and personal skills.

Overall, it appears that CDIO curriculum implementation at QUB over the past ten years has been accompanied by an increase in skill levels of graduates in several key areas. However, other areas still require further work to fully realise the benefits and aims of CDIO. Additionally, to meet expected technological and societal changes, further work will be carried out to assess the suitability of the current programmes for meeting the needs of industry and engineers as we move into the next 10 years and beyond.

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BIOGRAPHICAL INFORMATION

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