

Mapping “Digital Chemical Engineering” in the UK: A Sector-Level Audit of IChemE MEng Curricula

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ABSTRACT

The rapid shift toward Industry 4.0 and data driven manufacturing has prompted universities to reshape chemical engineering programmes, yet the scope and coherence of “Digital Chemical Engineering” (DCE) within UK curricula remain unclear. This study qualitatively maps DCE provision across five IChemE accredited MEng degrees to identify which digital skills are taught, how they progress across programme stages, how skills are distributed between core and elective content or taught versus applied learning, and how well provision aligns with accrediting frameworks. The analysis is structured around eight domains: (D1) programming and computation; (D2) data literacy and statistics; (D3) process modelling and simulation; (D4) optimisation and process systems engineering; (D5) control, automation and instrumentation; (D6) AI, machine learning and digital twins; (D7) software engineering practices; and (D8) data governance, ethics and cybersecurity. Results show institution dependent digital skills coverage. Some programmes introduce a broad digital skill set from Year 1, while others concentrate digital content in later years or adopt a more progressive distribution. Across institutions, D7 is consistently underrepresented. Foundational skills in D1, D2 and D8 are typically embedded throughout programmes, whereas more advanced domains D3 to D6 are introduced at later stages. Domains D1 to D4 demonstrate a stronger balance between teaching and application, while D5 to D8 are predominantly taught, with application increasing in later years. Optional fourth year modules play a significant role in shaping graduate digital profiles. Overall, DCE provision broadly aligns with IChemE and AHEP4 guidance, where expectations for D1 to D4 are more explicitly articulated

Keywords: Education, Industry 4.0, Modelling and Simulations, Choose an item.Choose an item., Digital Skills, Curriculum, Digital Chemical Engineering

INTRODUCTION

Digitalisation and Industry 4.0 are reshaping chemical engineering practice across the industries, with increasing reliance on data-driven decision-making, advanced modelling, automation, and digital twins [1]. These developments are transforming how processes are designed, operated, and optimised, and are redefining the skills expected of graduate chemical engineers. Historically, undergraduate programmes have introduced

students to well-established tools such as process simulation and basic programming, with the expectation that deeper digital expertise would be developed post-graduation in the workplace. However, recent studies and employer surveys indicate that this model is no longer sufficient. Employers increasingly report skills gaps in digitalisation and now seek explicit evidence of digital competence during graduate recruitment [2].

In response, universities are embedding digital skills like modelling, process simulation, coding and statistics

more deliberately within chemical engineering curricula [3], often in collaboration with industry and professional bodies. Nonetheless, there remains considerable uncertainty regarding what constitutes appropriate “Digital Chemical Engineering” (DCE) coverage, how digital skills should progress across degree programmes, and how consistently these expectations are implemented across institutions. While prior work has explored the pedagogical value of specific digital tools and surveyed academic and industrial perspectives on digitalisation in education, these studies largely focus on individual modules, tools, or localised curriculum reform [4-7].

Within the UK context, this issue is closely linked to accreditation requirements. IChemE accreditation establishes shared learning outcomes and standards for professional formation, while allowing flexibility in curriculum design. Accreditation guidance highlights importance of systems thinking, and the ability to work with modern engineering tools and data-rich environments [8]. However, it provides limited explicit direction on the depth, sequencing, or balance of digital skills across the curriculum, potentially leading to uneven provision between institutions despite a common accreditation framework.

This study provides a sector-level mapping of DCE coverage across MEng programmes in the UK that are accredited by the Institute of Chemical Engineers (IChemE) and in alignment with the Engineering Council’s Accreditation for Higher Education Programmes guidelines (AHEP4). This study evaluates the baseline for digital readiness in UK chemical engineering education and provides evidence to inform departmental curriculum review and the future evolution of accreditation guidance. The purpose of this work is to map DCE, provide an overview of the digital landscape, and draw potential trends, helping practitioners understand more about their curriculum. This work is not providing recommendations, ranking one approach over another or setting a precedence.

METHODOLOGY

Data Collection and Curriculum Mapping

Following from the outcome of a survey on the views on key skills for chemical engineers from academic and industrial stakeholders [2] and using informed judgement and discussions across contributors who are all heavily involved with curriculum design in their respective institutions, DCE provision was classified across eight domains: (1) programming and computation: ability to understand, write, and execute code. (2) data literacy and statistics: understanding of statistical principles, use of data visualisation for effective data communication. (3) process modelling and simulation: use of specialised software to develop models and simulate unit operations. (4) optimisation and process systems engineering: use of systems engineering principles and algorithms to identify

best possible variables. (5) control, automation and instrumentation: design and implementation of control systems to monitor and maintain process variables towards safe and stable plant operation. (6) artificial intelligence, machine learning, including digital twins: use of tools and software to identify patterns, development of virtual, real-time depiction of a process or plant that can be updated using process data, predict performance and diagnose issues in a simulated environment. In this context digital twins represent artificial intelligence or machine learning enabled, data-driven operational replicas of the process. (7) software engineering practices (version control, testing, reproducibility): tracking and managing changes to code over time, reverting to previous versions, ensuring reliable reproducibility. (8) data governance, cybersecurity, and ethics around digital tools: understand the importance of data storage, quality, security and access, address moral implications around the use of digital tools.

It is important to point out that the domains focus on elements of the curriculum directly related to digital skills, rather than fundamental chemical engineering knowledge that would be taught in traditional core modules. The Universities offering accredited degrees in chemical engineering or related courses at BEng and MEng level that participated in this curriculum mapping activity were: Aston University, University of Manchester, University of Nottingham, University of Sheffield, University College London (two departments each with their own degree programmes; Chemical Engineering (CE) and Biochemical Engineering (BE)). Representatives from each participating university in this study mapped the DCE curriculum provision for their offered courses in chemical engineering against each domain, per year of study (years 1-3 for BEng courses and 1-4 for MEng courses). This was done by analysing publicly available information in module descriptors and learning outcomes, supplemented on occasion by additional knowledge of modules and assessment based on their knowledge of teaching specific courses or from communications with academics involved in teaching specific courses. Each institution was responsible for providing and checking data for their course(s), with all data being collated in a shared document. DCE curriculum mapping was done in a qualitative manner at this stage, indicating a “yes/no”, and providing examples or comments of how each domain content is covered where relevant. With the understanding of content being covered formally in the curriculum, i.e. core/taught and formatively assessed as a learning outcome, and informally, as by-product/applied, i.e. taught but not assessed, or implicitly expected in later years of study, mapping was designed to recognise both dimensions. It is important to note that the mapping was done by a representative academic of each university rather than all module leaders of all courses,

hence there might have been details on specific learning activities or assessments that were overlooked or underestimated. This could result in the mapping not being completely definitive, but nevertheless sufficient to highlight trends and perhaps differences in DCE coverage across the examined curricula. In addition to curriculum mapping, publicly available IChemE and AHEP4 accreditation guidelines [8, 9] were mapped against the domains.

Data Analysis and Visualisation

Once mapping was completed qualitatively, it was assessed and validated through comprehensive discussions across all collaborators to ensure as much uniformity as possible, a scoring system was introduced, to bridge the qualitative mapping with a quantitative approach. An “instructional intensity” metric was developed to distinguish between the presence of a tool and the formal pedagogical delivery of a skill. Each module-year intersection was evaluated against two criteria:

- **Core/Taught (Primary Intensity):** The domain is a formal part of the curriculum with explicit, assessed Learning Outcomes. Students receive dedicated instruction (e.g., a Python module).
- **Byproduct/Applied (Secondary Intensity):** The domain is utilised as a tool for another engineering subject (e.g., using Excel in a lab report) without new formal instruction.

For the purpose of the **Digital Maturity Curve**, the Index focuses on **Core/Taught** instances, representing the “Instructional Load” of new digital competencies introduced at each level. The quantification process followed a three-step aggregation logic:

1. **Binary Mapping:** Each of the eight domains was assigned a binary value (1 for Core instruction, 0 for absent) for every university at every level.
2. **Summation and Normalisation:** For a given Academic Year (Y), the raw intensity score (S_y) was calculated as the sum of active domains across all participating institutions (n):

$$S_y = \sum_{i=1}^n \sum_{d=1}^8 D_{i,d}$$

Where $D_{i,d}$ is the binary state of Domain d at University i. S_y was used for calculating scores and generating the Digital Coverage Heat Map (Figure 1) and the Digital Maturity Curve (Figure 4).

3. **Weighted Aggregation:** To account for elective specialisations in Year 4, the score was bifurcated into Core Intensity (mandatory/core modules) and Potential Intensity (elective modules).

For the construction of the Digital Coverage Heat

Map, the scale range was defined from 0 to 3. (0) corresponded to absence of evidence, moving to evidenced presence of domain activities as curriculum by-products with no formal assessment (1) and as optional modules including assessed learning outcomes (2), and ending with evidenced domain activities in core modules with formally identified learning outcomes (3). For the accreditation guideline mapping, absence of a specific domain was marked with 0, 1 corresponded to vague reference and 2 corresponded to clear evidencing of a domain to the accreditation guidelines. Data was processed and analysed using Python (version 3.14.2) for visualisation and trend identification per domain and per year. It is important to note that the quantitative analysis (scoring) was performed by one member of the team, to ensure consistency.

RESULTS AND DISCUSSION

Analysis of the digital curriculum heatmap (Figure 1) revealed substantial variation in the breadth and depth of digital skills coverage across universities and degree levels. Across all five universities, digital domains traditionally embedded within chemical and process engineering curricula, namely process modelling and simulation (D3) and control/automation and instrumentation (D5), were the most consistently represented. These domains were commonly embedded as core assessed modules or optional assessed offerings particularly in senior programme years. Data literacy and statistics (D2) was also widely present across almost all universities, typically embedded within assessed modules. In contrast, under emerging digitalisation domains (e.g., AI/ML and digital twins (D6), software engineering practices (D7), and data governance, ethics and cybersecurity (D8)), coverage was considerably more even. These domains were frequently either absent or delivered indirectly without assessment and appeared in isolated cases rather than as integrated features of coherent programme pathways.

Institution-level patterns further highlight the uneven digital landscape. Aston demonstrated relatively strong provision in D1-5, and D8 from the early years through to MEng level, yet provided limited coverage of D6, with some provision in Year 1 and more application or presence in optional modules in later years. Manchester showed a similar pattern, with strong coverage in D3-5 and limited progression in emerging domains; D6 appeared only in two units with formally identified learning outcomes. At Nottingham, D2 and D3 are embedded and assessed throughout the programme. D1 develops progressively, while D4 and D5 are mainly introduced in later years. In contrast, D6 is only indirectly addressed, and D8 appears only at MEng level. Sheffield exhibited strong coverage of D2-3 and D8 throughout the curriculum and intermittent coverage of D1, D4-5, while D6 and D7 had

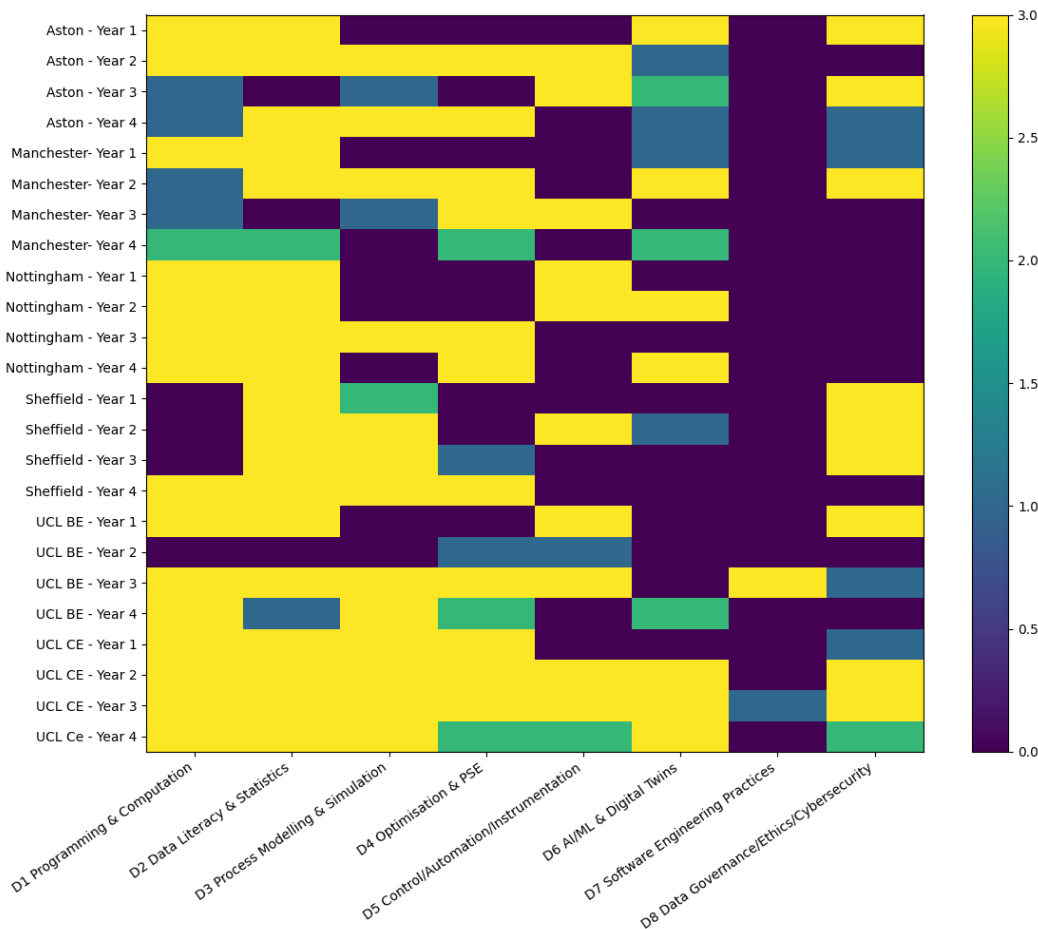


Figure 1. Heatmap of curriculum digital coverage across examined programmes at the five Universities, per year of study and domain. Scale range is from 0/dark blue indicating absence of coverage to 3/yellow indicating skill covered by formally identified learning outcomes.

limited evidence of engagement. UCL, across both bio-chemical (BE) and chemical engineering (CE) routes, presented strong late-stage coverage in D1-5, but did not incorporate substantive coverage of D7. UCL BE's biology-focused modules differ from traditional chemical engineering due to the department's distinct remit and scope, and while a digital agenda is embedded throughout the programme, its unique nature leads to observable differences compared with conventional chemical engineering curricula. UCL CE showed strong inclusion of D1-4 throughout all years of the degree programme, whilst domains D5, 6 and 8 were included in Year 2 onwards exemplifying a significant digitalisation emphasis.

Digital skills coverage demonstrates institution-dependent sequencing. Some universities (e.g., UCL) introduce a broad range of digital competencies from Year 1, whereas others (e.g., Nottingham, Sheffield) concentrate digital learning in senior years and a third group (e.g., Aston, Manchester) distribute coverage more progressively across the programme.

Further analysing the spread of digitalisation skills in

the degree programme, Figure 2 shows an overall mean convergence score for each domain in each year across all degree programmes considered in the study. From this four approaches to how domains are covered can be identified:

- Coverage is consistent and significant across the degree programme - D1, D2, D8
- Coverage is initially low and is built up throughout the degree programme - D3, D4
- Coverage is focused most significantly in a specific year or two - D5, D6
- Coverage is very limited - D7.

It is clear that core digital skills of D1 Programming and Computation and D2 Data literacy and statistics are covered immediately in year 1 and that these skills are continually included and built upon throughout the degree programme. This is reasonable since these skills align with core mathematical knowledge that students

develop and apply throughout their studies.

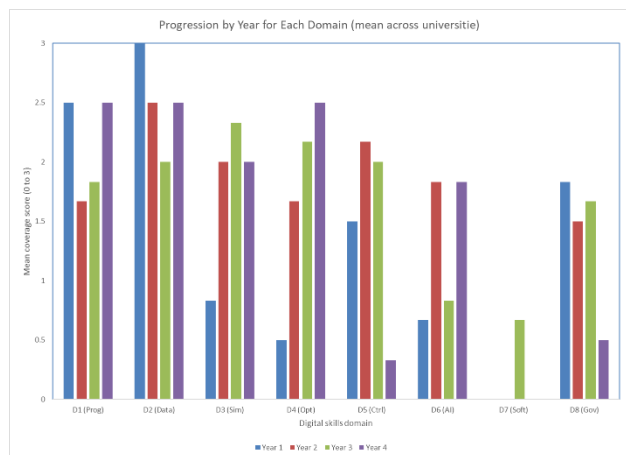


Figure 2. Progression of domain coverage per year of study across D1-8. D1: programming and computation, D2: data, literacy and statistics, D3: process modelling and simulation, D4: optimisation and PSE, D5: control automation and instrumentation, D6: artificial intelligence, machine learning and digital twins, D7: software engineering practices, D8: data governance, ethics and cybersecurity.

Interestingly, Figure 2 shows that Data Governance, Ethics, Cybersecurity (D8) is represented in each year with almost equal coverage of D8 in year 1 compared to year 2 and 3, although with a drop in year 4. The heat map in Figure 1 shows D8 to be included in the degree programme when many digital skills have yet to be taught or developed. This could be explained through the open-ended interpretation of data governance, ethics and cybersecurity. It is likely that some form of cybersecurity and GDPR training is included in introductory courses as part of induction training. However, specific relation of these domains to chemical engineering, such as the impact of a breach of cybersecurity in the safe operation of a chemical plant and recommended mitigating actions are likely not included until later years, if at all. Equally, interpreting ethics is also considerably open-ended. It can be acknowledged that some form of ethics is included at the start of the degree programme, specific inclusion of ethics related to digital skills cannot be guaranteed but equally cannot be ruled out. For example, the ethics of the use of AI in one's studies or the ethical impact of using AI on a workforce in a mini design problem could be included at the beginning of the degree programme. Specific information to rule these considerations in or out based on information available in published module descriptions and intended learning outcomes, which are often limited in number and format by individual university regulations, can be the cause of varied interpretation of this domain.

Considering domains that are initially covered less

and built upon throughout the degree programme seem reasonable when the specific domains are examined. Process Modelling and Simulation (D3) and Optimisation and PSE (D4) are more advanced applications of digital skills once more fundamental digital, mathematical and process unit operation skills are introduced earlier in the programme. Equally, considering domains that have a focus in a specific year or two, such as Control/Automation/Instrumentation (D5) and AI/ML and Digital Twins (D6) is also reasonable since this aligns with material and prior knowledge to which these domains relate. For example, Control/Automation/Instrumentation is often introduced, taught in detail and applied once initial concepts have been introduced, but are then less of a focus in electives in later years. On the other hand, considering D6, there seems to be a focus in year 2, which is not then revisited until digital-focused electives in the final year.

Finally, there is consideration of domains for which there is little recognition throughout the degree programme, such as Software Engineering Practices (D7) with only some indication of coverage in Year 2 or 3 at a couple of universities. This may be down to how the domain itself is formulated and the implicit inclusion of this domain to achieve learning outcomes of other domains. For example, software engineering practices, such as tracking and managing changes to code or documents over time, are not an explicit learning outcome of specific modules, but successful software management is needed to carry out large, open-ended, group design projects and meet the D3-related learning outcomes.

Looking at the DCE coverage across core/taught components where defined learning objectives were used to assess student learning, and curriculum by-products/applied where understanding of tools and knowledge taught at earlier years was assumed and students were expected to apply it to solve problems, there is an interesting trend revealed (Figure 3). There is prominence of distinct Digital Domains in both teaching and of application and the striking underrepresentation specific digital domains in the curricula.

Software Engineering Practices (D7) including open-source code sustainability, version control, testing, reproducibility are minimally integrated across the programmes investigated. This is followed by Data governance, Cybersecurity and Ethics (D8) and AI/ML and Digital Twins (D6) domains, which are primarily taught as part of the core curriculum. In contrast, Programming and Computation (D1), Data literacy and Statistics (D2), Process modelling and simulation (D3) domains are overrepresented in both the taught and the applied components of the curriculum, followed by Optimisation and Process Systems Engineering (D4) and Control, Automation and Instrumentation (D5).

An interesting aspect of our analysis elucidated the sensitive balance between the taught and the applied

components of the content covered in these domains.

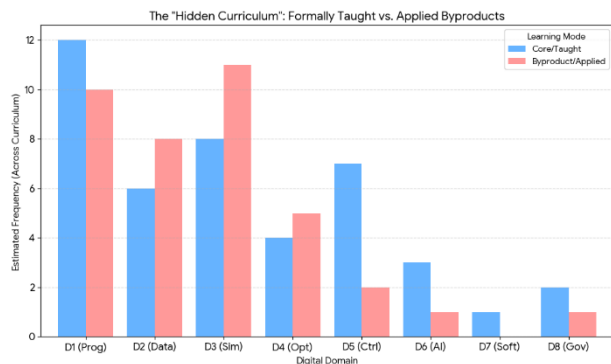


Figure 3. Comparison between DCE coverage across all domains for core/taught components and components evidenced as byproducts.

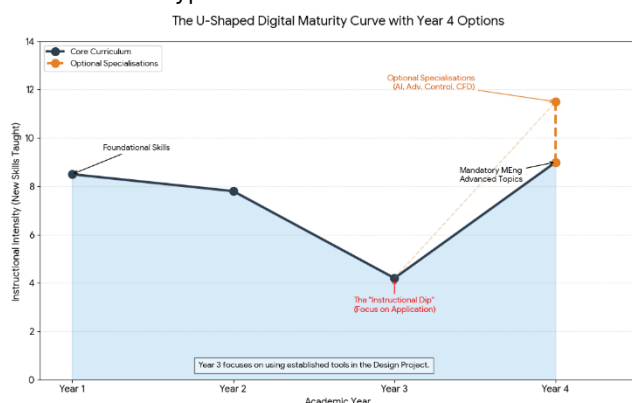


Figure 4. Digital “maturity” curve of DCE provision.

We note that the digital content is not only taught and assessed but has become an integral part of the learning curriculum since they are frequently utilised as part of the application demanding their use, even without necessarily being assessed directly. We observe a heavy focus on application in domains D2-4, possibly emerging from the nature of the digital capabilities covered by these domains. Concepts such as data science, process modelling and simulation and optimisation, once basic concepts are introduced, mostly remain applied concepts in the curricula in a range of areas, consequently serving to support digital capacity building and training primarily through application. These domains are closely followed by D1. While D1 and D3 find a wide range of application areas as expected, they are also an integral component of the core teaching of the curriculum and are widely implemented across different programmes.

Looking at the totality of DCE coverage from a progress-per-year point of view (Figure 4), another interesting trend emerges across the four years of study, highlighting a “U” shape maturity trendline. The left peak (Years 1 and 2) is the “Input Phase.” Universities front-load digital skills (Python, MATLAB, Excel, Statistics) to ensure students have the “mathematical literacy”

required for engineering science modules. In this phase, new digital competencies are introduced. The curve dips in Year 3 because the focus shifts from learning new digital skills to applying existing ones (primarily for the high-stakes Design Project).

Students are at their busiest digitally, but they aren't learning new software; they are refining their use of Aspen Plus or HYSYS. From a “new instruction” perspective, digital maturity appears to stall before spiking again in Year 4 with advanced industrial specialisations like AI and Molecular Modelling.

For MEng students, the curriculum in many cases introduces high-level concepts that are currently industry-leading, such as Machine Learning, Computational Fluid Dynamics, and Digital Twins. While the core Year 4 curriculum already sees a resurgence in digital instruction (e.g., mandatory Advanced Process Control, Computational Modelling, or Sustainability Modelling), the dotted line shows the peak maturity reached through electives like Advanced Machine Learning (AI), Computational Fluid Dynamics, and Digital Twin Design. It should be noted that the “gap” between the solid and dotted points at Year 4 highlights that digital competency in the final year is highly dependent on student choice, allowing for a deeper technical “spike” compared to the broad foundational skills of Years 1 and 2. It should also be noted that during this analysis we did not account for cases where the final year research project, the highest credit-contributing module in Year 4, was purely focused on one or more of the DCE domains rather than on research areas not as heavily intertwined with digitalisation.

Having completed the DCE mapping of the curricula of participating Universities, the eight domains were used to map the degree accreditation guidelines from the IChemE and AHEP4, marking absence of mention as a 0, vague mention as 1 and clear coverage as 2 (Figure 5).

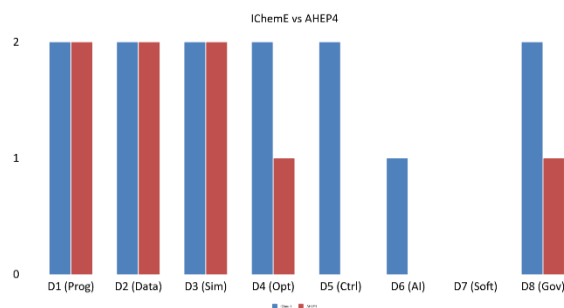


Figure 5. Mapping of IChemE and AHEP4 accreditation guidelines.

The IChemE provides information that effectively discusses the need for educational provision when it comes to domains D1-5. For AI/ML and Digital Twins (D6) the guidelines of “AI approaches” that can very vaguely

link to this particular domain.

When it comes to Software engineering practices (D7), it is unclear whether the accreditation guidelines include this domain. The guidelines mention the need to "understand system dynamics, being able to determine the dynamic response to changes in a process, design measurement and control functions, and determine its performance" which can vaguely link to D7 but not clearly. Last but not least, while there is clear mention of the need for prospective graduates to become aware of ethical considerations, there is no explicit mention or relevance to ethics around the use of digital tools. When it comes to big data or or cybersecurity there is acknowledgement of how the profession is changing.

A notable difference between the IChemE and AHEP4 accreditation guidelines is that whilst D1-4 are clearly covered under both schemes, D5-D7 are not mentioned in the AHEP4 guidelines. This could be because at least D5 and D6 might be deemed discipline-specific while AHEP4 caters for all engineering disciplines. When it comes to data governance, cybersecurity and ethics, AHEP4 mentions the importance of ethics, but not necessarily relating that to the digital space.

REFLECTIONS

The DCE curriculum mapping of the Universities participating in this study shows clear trends in the provision of education on digital tools. Undeniably, all programmes considered have embedded the majority of the eight examined domains in their curriculum, at different years of study and in different ways, following accreditation guidelines. What is interesting to note is that there is very limited coverage of Software Engineering Practices (D7) across the studied programmes, which also aligns with the absence of this domain from the accreditation guidelines. This could potentially be attributed to limited relevant educational capabilities across module leaders, or even to the fact that this domain, at least within the remit of chemical engineering, has not been a well-established area to allow for development of relevant educational content. The lack of D7 presence in the chemical engineering curriculum could be pointing towards the need for faster adoption of industrial needs within taught curricula and provision of training to educators when it comes to digital tools, with the aim of ensuring the more holistic preparation of future workforce.

It is worth pointing out that while mapping the curricula it became evident that ensuring accurate DCE mapping in terms of domain presence and intensity was cumbersome. This could be attributed to the "hidden curriculum" effect where it was tricky to differentiate between taught content that was formally assessed and content that was expected to be understood and applied

but without formal assessment for a particular module. Furthermore, in complex module cases, such as the Design Project and Research Project that students usually undertake in Year 3 and Year 4 respectively, this effect was even more evident, as there are cases where such modules could contain very strong digital-focused components at an individual level rather than a cohort one. Accreditation guidelines indicate the baseline programmes are expected to evidence around learning outcomes and specific attributes; however, there is no expectation of where in the curriculum such elements should be embedded, or the intensity of their coverage. For a discipline with such profound industrial relevance, it is imperative for educators to work closely with accrediting bodies and industry, and continually track industrial needs, ensuring that the attributes of graduate chemical engineers are on par with the professional expectations. Furthermore, it is relevant to note that updated IChemE accreditation guidelines, which align more explicitly with AHEP4, will be released in the coming year.

CONCLUSIONS AND FUTURE WORK

This work has revealed that there is substantial variation in the breadth and depth of digital skills coverage for domains 1 to 6 and domain 8 across institutions and programmes evaluated. However, all programmes evaluated showed limited coverage of domain 7 on software engineering practices, followed by domain 6 on ML/AI and digital twins. This evidence shows the misalignment of the provision of these emergent skills with the evolving industrial sector.

Traditional digital domains aligned with core mathematical knowledge such as programming and computation and data literacy and statistics (D1 and D2) are commonly introduced in the first year of the programmes. Process modelling and simulation and optimisation, process systems engineering, control, automation and instrumentation and AI/ML and digital twins (D3-6) however are preferentially introduced after students are familiarised with process unit operations and fundamental programming skills. Governance, ethics and cybersecurity are covered evenly across the first three years, but more enquiry on the scaffolding in depth and specialisation in this domain is required to understand the student readiness for the sector. The provision of digital skills shows a front-loading in year 1 and 2 mainly related to inputting domains D1 to D5, followed by a drop in year 3 where application takes the main stage. Finally, in year 4 the incorporation of advanced chemical engineering skills and specialisation introduces a new instruction phase in the learning of digital skills.

Domains early introduced in the programme and traditionally requested by the IChemE accreditation (D1-D4) show a good balance between being taught and being

embedded, integrated and largely applied in later stages. On the contrary, domains D5-8, which are introduced at later stages, are mainly being taught with lesser opportunities for application. Overall, the digital chemical engineering provision broadly aligns with IChemE and AHEP4 guidance, where expectations for D1 to D4 are more explicitly articulated.

The present work is a cornerstone in the mapping of digital skills that has evidenced the need to enquire about potential barriers affecting underrepresented domains such as domain 7. It also underscores the importance of examining further the breadth and depth for all domains through a more comparative quantitative or semi-quantitative analysis across the years and institutions. The intention of this work is not to provide recommendations but rather provide an overview of digital skills presence in chemical engineering education. The insights generated here will support future evaluation of how programmes align with the forthcoming IChemE accreditation guidelines, which integrate expectations from the Engineering Council's AHEP4 framework, and may ultimately serve as a tool for assessing digital-skills provision within accredited chemical engineering programmes and sector needs.

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