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Impact of Curricula on Student Learning: A Comparison of Six Chemical Engineering Programmes in Three Washington Accord Countries

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Working paper no. 101
August 2023

UKRI Economic and Social Research Council

UKRI Research England

Published by the Centre for Global Higher Education,
Department of Education, University of Oxford
15 Norham Gardens, Oxford, OX2 6PY
www.researchcghe.org

ISSN 2398-564X

The Centre for Global Higher Education (CGHE) is an international research centre focused on higher education and its future development. Our research aims to inform and improve higher education policy and practice.

CGHE is a research partnership of 10 UK and international universities, funded by the Economic and Social Research Council, with support from Research England.

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Contents

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Abstract

This paper shows the variations in the day-to-day structuring of engineering curricula in three Washington Accord countries – England, South Africa, and the United States. Herein we also show how these variations influence students' learning experiences. The curricular parameters that we focus on include weekly contact hours, curricular rigidity, and the structure of the first year of the degree. Findings obtained through an analysis of undergraduate handbooks, weekly timetables of the different courses, and student interviews suggest considerable differences across the engineering programs along these parameters, both within and across national boundaries, which influence students' experiences of learning engineering. A high contact time, especially during the initial years of the degree, limits students' capacity to self-study and participate in extra-curricular activities. The ability to choose electives and specialisations allow students to diversify their skillsets. Where a program introduces a significant number of courses specific to chemical engineering from the first year, students tend to build an early understanding of the discipline. However, this limits their capacity to change majors.

Keywords: ABET accreditation criteria; Chemical engineering; Curricular differences; Outcome-based education; Student experiences with curriculum; Washington Accord

Acknowledgment: This article is from the Centre for Global Higher Education (CGHE) Understanding Knowledge, Curriculum and Student Agency Project. We acknowledge the contribution of the other project team members: Paul Ashwin, Jenni Case, Jan McArthur, Reneé Smit, Janja Komljenovic, Alaa Abdalla, and Benjamin Goldschneider. The support of the Economic and Social Research Council and Research England (grant references: ES/M010082/1, ES/M010082/2 and ES/T014768/1) and National Research Foundation, South Africa (grant reference: 105856) are gratefully acknowledged along with support from CGHE.

Introduction

The connection between advancement in engineering and innovation and economic growth is well established in both developed and developing countries (Centre for Economics and Business Research, 2016; Matthews et al., 2012). In the debates on engineering education, curriculum occupies an important place. It is generally agreed that engineering curricula are in the need of reform to address several issues including attracting and retaining more students; improving the diversity in engineering; and enhancing graduate preparedness by better training engineering students to serve the needs of the industry (Council on Higher Education, 2013; Graham, 2012, 2017; Jamieson & Lohmann, 2012; Morgan & Ion, 2014).

The links between the engineering curricula and how they influence students' experiences and choices has been previously studied. Stevens et al. (2005, 2008) note that students' experiences of navigating through an engineering degree is closely related to what they call "navigational flexibility" at a university. Through the examples of different students, they highlight that at institutions where there was limited flexibility in the curriculum in taking courses outside engineering, students either struggled to complete the engineering coursework while also taking courses based on personal interest or followed a pre-determined plan of study as recommended by their departments. Additionally, students with sufficient time outside of engineering courses were motivated to take non-engineering courses according to their interest even though they did not necessarily count towards their engineering degrees. Similarly, Lichtenstein et al. (2009) highlight that a curricular structure that affords students flexibility in choosing majors and taking courses outside of the chosen major allows them not only to explore other majors but also easily shift majors by leaving engineering.

Several other studies have highlighted the role of specific curricular features in shaping engineering students' experiences. For example, Mann et al. (2009) show that project-based learning in the curricula can help students better learn professional engineering skills such as teamwork and project management. Kotys-Schwartz et al. (2011) note that service-learning can lead to an increased knowledge of the subject matter and gains in critical thinking, problem-solving skills, teamwork, and communication among students. Along similar lines, internships and co-ops can help students better understand theoretical concepts by seeing their practical implementation (Mann et al., 2009). They can also help students self-evaluate their interest in pursuing and engineering career (Matusovich et al., 2010) and competence in being a successful engineer (Matusovich et al., 2008).

One significant facet of the ongoing discussions on curricula reform is the facilitation of movement of engineering graduates between countries. This need has led to the creation of global accreditation requirements (Case, 2017) which have been achieved through, for example, the mechanism of the Washington Accord. Established in 1989, the Washington Accord initially aimed at mutual recognition of undergraduate engineering programs in the participating countries. The initial signatories to the Washington Accord included Australia, Canada, the Republic of Ireland, New Zealand, the UK, and the US. Since 1989, the Washington Accord has spread across the globe. However, the European Union, most of Latin America, and most African countries are still not signatories (Lucena et al., 2008). In the European Union, the alignment of curricula across countries facilitating international movement of engineering graduates is achieved through the Bologna agreement signed in 1999 (Adelman, 2009; Case, 2017). In recent years, there have been increased efforts to link more countries to global accreditation with Peru joining the Washington Accord in 2018, Costa Rica in 2020, and Chile gaining provisional signatory status in 2018 (Washington Accord, 2020). In Africa, substantial differences remain in engineering programs with Anglophone and Francophone nations reflecting the degree structures of their colonisers (Case, 2017). To date, South Africa, who joined in 1999, remains the only signatory from Africa (Washington Accord, 2020).

The Washington Accord is closely based on the accreditation criteria of the Accreditation Board for Engineering and Technology (ABET). Membership to the Accord requires the participating countries to accredit their engineering degrees to a similar set of criteria (Case, 2017). ABET’s own accreditation criteria have changed over the years. The initial ABET criteria focused on inputs; the emphasis has shifted to an outcome-based approach through the adoption of the Engineering Criteria 2000 (ABET, 2002). The Engineering

Criteria put more emphasis on clearly articulating program objectives and learning outcomes while reducing detailed specifications on the content of the engineering curricula (Prados et al., 2005). As a result, the accreditation requirements for engineering programs, which are being adopted by an increasing number of countries across the world, have adopted an outcome-based model since 2000.

This focus on learning outcomes has considerably influenced the design of curricula across undergraduate engineering programs at different universities in countries that are signatories to the Washington Accord. These programs have deliberately incorporated various elements into the curricular structure to meet the accreditation requirements such as ensuring appropriate coverage of engineering topics such as engineering science and design, including modules on mathematics, science, and general education, and incorporating a capstone project that requires students to use the knowledge and skills from the previous coursework (e.g., see Buyurgan & Kiassat, 2017; Chandrasekaran et al., 2013; Meah et al., 2020).

As a result of adopting the outcome-based approaches through accreditation requirements, there has been some homogenization of undergraduate engineering curricula across national boundaries. However, this homogenization has generally been at a level of the overarching structure of the whole degree rather than the specifics of particular course curriculum. For example, most Washington Accord programs are four-year degrees allowing similar development towards the outcomes. There is some variation, in England, the Washington Accord equivalent is a three-year bachelor's plus a one-year master's program, or an integrated four-year master's degree. South African Washington Accord programs are typically four-year bachelor's degrees despite the national norm of three-year degrees. Additionally, most degrees incorporate various "practice" type elements such as capstone projects in the curriculum and assessment of these tend to aim to directly demonstrate outcome achievement. Accreditation requirements have also ensured that the curriculum meets the requirements of incorporating certain disciplinary content, i.e., courses on mathematics, science, or humanities (Chandrasekaran et al., 2013; Jawitz et al., 2001). The reason for homogenisation of engineering curricula at a degree level is that the Engineering Criteria 2000, which was a significant starting point for the formulation of these global accreditation criteria "emphasise learning outcomes, assessment, and continuous improvement rather than detailed curricular specifications" (Prados et al., 2005, p. 165).

Nonetheless, the adoption of outcome-based approaches have allowed undergraduate engineering programs to meet the global standards while preserving institutional autonomy and alignment with national requirements and engineering cultures as illustrated by Klassen and Sá (2020) in the study of three Canadian schools of engineering. Similarly, Downey et al. (2006) highlight how the engineering problem solving varies between countries, which in turn influences the design of the engineering curricula. They note that the engineering curricula in the UK emphasize the use of engineering knowledge in solving practical problems, while the focus is on using the first principles in France and attaining a high degree of precision in Germany to do engineering work. In the US, the engineering curricula have been significantly influenced by the technical needs of the country during the Cold War period, and consequently incorporated a high level of mathematics and engineering science to produce cutting-edge technologies such as computers, jets, and rockets to meet the needs of the military (Seely, 1999). Along similar lines, given the diversity of the student population in terms of backgrounds and preparedness for university education, the Council on Higher Education (2013) in South Africa has also advocated for a flexible curriculum for higher education (including engineering education) in the country. This flexible curriculum is intended to suit the needs of a diverse set of students with different levels of preparedness by allowing them to complete the degree requirements at different speeds according to their needs and preferences.

It is thus clear that the accreditation requirements allow a considerable scope for incorporating particular requirements while maintaining institutional autonomy. It follows then that there could be considerable differences in how undergraduate engineering curricula are structured at the micro level in terms of credit requirements, contact time, hands-on and experiential learning activities, and the incorporation of interdisciplinary courses across national and institutional lines.

While prior studies have highlighted how engineering curricula meet both local and national requirements (e.g., Downey et al., 2006; Klassen & Sá, 2020) and accreditation requirements (e.g., Buyurgan & Kiassat, 2017; Chandrasekaran et al., 2013; Meah et al., 2020), this literature highlights the structuring of and the variation in the engineering curricula at the macro level, i.e., at the level of the entire degree. Within chemical engineering specifically, comparative studies have been done to highlight the different ways of teaching certain aspects of the degree and an increased or reduced emphasis on some topics (Voronov et al., 2017; Yao et al., 2022). This study expands this literature by exploring the structures of undergraduate engineering degrees at the micro level that concerns students' day-to-day involvement with classes and ability to make decisions in terms of choosing courses and specializations within the degree. At the same time, this paper explores how these micro-level curricular features shape students’ experiences of learning engineering. This information may help educators and institutions make more informed decisions in the design of engineering curricula.

This paper focuses on the structures of six chemical engineering programs in three different countries, two each in England, South Africa, and the United States. All of the programs are four-year degrees accredited under the Washington Accord. The paper highlights the similarities and differences across these programs in terms of contact hours, flexibility in the curricula, and the structure of the first year of the degree; and their influence on students’ experiences. The reason for choosing chemical engineering for this study is twofold: 1) This paper is part of a larger project that seeks to understand undergraduate students’ engagement with disciplinary knowledge in two different STEM disciplines – chemistry and chemical engineering. Given these two disciplines share a large body of knowledge, the larger project aims to compare how the disciplinary knowledge is delivered to students in these disciplines, and how students’ interaction with their disciplinary curricula develops their student agency and shapes them as disciplinary professionals (Ashwin, 2019). While analysing the intricacies of the six chemical engineering programs that are a part of the larger project, we found that there are significant differences in the structure of the curricula of these programs all of which fall within the Washington Accord, thus motivating the topic of this paper. 2) Chemical engineering is both a traditional and an important engineering discipline. It was formally established as a discipline more than a century ago (van Antwerpen, 1980).

Theoretical Framework

The work of the sociologist Basil Bernstein (2000) on recontextualization of disciplinary knowledge into curriculum provides the theoretical underpinning for this work. Bernstein distinguishes the disciplinary knowledge from the curriculum in any field, and argues that the disciplinary knowledge is converted into the disciplinary curriculum through a process of recontextualization. He notes that this process of recontextualization is not straightforward. Rather it represents an area where power relations and interests come into play. These power relations and interests include the influence of academics, institutions, disciplinary societies, professional bodies, employers, and government and funding agencies. Based on the varying priorities of these different stakeholders, the disciplinary knowledge can be recontextualised into curricula in several ways. Hence, there are a multitude of ways in which the curriculum can be organized and delivered to the students. This is remains true for high-consensus disciplines like science and engineering, which have broad agreement on the basic tenets of knowledge. This theoretical lens has been previously applied by Case et al. (2016) to explore the influence of the national and the institutional contexts on the development of engineering curriculum in three different engineering programs across three countries.

Given that the different stakeholders influence the structuring of the curricula, it follows that there would be differences in the day-to-day structuring of the curricula across different national and institutional contexts. This exploration of curricular differences across contexts, along with their influences on students' experiences, is the focus of this paper. This exploration and elucidation will provide engineering educators with empirical examples of different ways of structuring the curricula, thus helping them make more informed decisions about curricular design.

Methods

Data for this study were collected from six universities across three countries. All institutions are publicly funded and have been given pseudonyms of chemical elements to reflect the focus of the study. Table 1 provides the details about these six universities in terms of their locations.

Table 1: Details of research sites

Country	England		South Africa		The US	
University Pseudonym	Erbium	Europium	Sodium	Samarium	Argon	Astatine

These data were collected as part of a larger international project that seeks to understand how STEM students engage with disciplinary knowledge in two different STEM disciplines – chemistry and chemical engineering (Ashwin, 2019). The overarching interest of the broader project is the development of student agency and knowledge gain. Thus, the focus of this paper is on elements of the curricula which can be directly linked to student experience. The analysis herein thus is an important component of interpretation of the larger project but the variation discovered is of sufficient interest to be a useful contribution to the engineering education literature.

The data analysed for this paper were drawn from two sources: 1) curricular documents such as undergraduate handbooks that detailed the degree requirements in terms of core and elective courses and weekly contact times of the different courses that students needed to take to complete the degree requirements, 2) annual semi-structured interviews with up to ten students per research site conducted throughout the course of their degree, which captured students' experiences with their courses and assessment practices, relationship with the discipline, engagement in co- and extra-curricular activities, and future plans after the completion of their degrees.

A preliminary analysis of the curriculum data from each institution and wide-ranging discussions among the authors about possible curricular variations led to a variety of potentially significant curricular features. Through iteratively focusing on and refining the definitions, three features of the chemical engineering programs were identified that clearly illustrate the links between curriculum and its influence on students' academic experiences. These curricular features included contact hours, curricular rigidity, and first year of the degree. While these features are not exhaustive, they are illustrative of the distinctions between programs.

The next step of analysis included preparing weekly timetables and the four-year degree plans taking into account the different elective and specialization options, which was primarily done by the second author in close consultation with the first author. Reference was made to university handbooks to obtain details about compulsory, elective, and specialisation courses and their weekly contact times. The decisions made by the first two authors to quantify contact hours or elective and specialisation requirements or first-year credit requirements in cases of ambiguities were achieved through discussion. The final set of decisions were then considered by all the five authors and any disagreements were resolved through conversation with referral to curriculum documents.

To compute contact hours, average weekly contact time was calculated for each year of study and each program. Sessions scheduled in alternate or intermittent weeks alongside regular contact time were averaged across the term or semester. Atypical weeks (such as examination periods or field trips) were excluded, as were any sessions without a specified schedule. The latter exclusion is often evident in the third and fourth years of study when students may be completing projects and other assignments during unscheduled laboratory work.

The reason for choosing weekly contact hours as opposed to the total contact time over an entire semester or an academic year is that we wanted to choose a criterion that relates to students' day-to-day academic experiences and interaction with the academic timetable. A cumulative measure over an entire semester or an academic year can hinder this understanding as it is the weekly contact time that can either enable or inhibit choices of electives, part-time employment or extracurricular activities, and can also drive different approaches to teaching and learning. Semester and year totals can disguise these variations over the course of the program.

For curricular rigidity, we wanted to explore the extent to which the degree is constrained by compulsory courses must be completed by all students and the extent to which students have some freedom of choice. All institutions use the notion of credits to designate workload. Hence the unit of measure used here was the course credit. Since the definition of a credit varies across institutions, we quantified fractions of a curriculum in terms of the university's own allocations of credits. We therefore define the rigidity of a curriculum in terms of the fraction of course credits that are compulsory for all students in the program. We chose curricular rigidity as a construct to analyse the curricula as opposed to curricular flexibility because all institutions have a similar conception of compulsory courses making rigidity an easily measurable construct. By contrast, the non-compulsory features that provide curricular flexibility take various forms, making flexibility more difficult to consistently quantify across curricula.

To analyse the degree to which students are exposed to the discipline-specific content in the first year, we compared the first year of the chemical engineering programs to another engineering program: mechanical engineering. Mechanical engineering was chosen as it was common across all the six institutions. By calculating the proportion of first-year course credits that each chemical engineering curriculum shares with another discipline, we quantified how much of the first year of engineering degree in each program is discipline-specific and how much is common.

Once we identified the three curricular features and quantified the curricular differences across the programs under study, the next step involved reading through the interview transcripts to identify instances that connected student experiences with these three features. The initial identification of relevant interview excerpts was done by the first author, which was then cross-checked by the third author. It should be noted that since the interview questions explored students' broader curricular experiences, there was ample scope for students to recount experiences that challenged our findings. However, except for the student experiences related to the first year of the degree, we did not find instances where these experiences diverged. Also, it should be noted that not all students talked about the influence of all three curricular features on their experiences, and hence the findings from the qualitative analysis of interviews provide exemplars of experiences rather than establishing prevalence among all students. Moreover, the paper does not use student data to strengthen the analysis of curricular differences, rather the interviews are used to illustrate the patterns that were found in the analysis of curricular data.

Findings

Our investigation of curriculum documents highlights three themes that were common across institutions and national contexts. We also saw evidence of difference among these contexts as well. In this section we will discuss these themes: contact hours, curricular rigidity, and first year of the degree in terms of how they were illustrated across institutions and countries. Following the discussion of each theme, we describe how the curricular feature shaped students’ experiences using interview quotes as evidences. Pseudonyms are used to refer to individual students.

Contact hours

One notable difference between the curricula among all the sites is the amount of contact time required of students. Though all programs are four-year programs, the time that students must spend in a classroom or laboratory varies significantly. To illustrate differences in contact hours, we chose to focus on average weekly contact time as the indicative measure.

There are two ways in which student choice impact the contact hours (discussed in detail in the section on curricular rigidity). Firstly, some universities offer explicit variations on the chemical engineering program in the form of specialisations, such as environmental science or biochemistry, that include different courses. The averages presented here exclude these options and focus on the traditional or mainstream chemical engineering curricula. Secondly, some of the chemical engineering programs incorporate electives: courses that students can select from a range of options. Where an explicit list of options was provided in the university documentation, the option with the least contact time was used. Where elective requirements were more open (e.g., allowing students to select from any qualifying course offered at the university), values were chosen based on a brief survey of qualifying courses. For example, if the university required students to take a three-credit course, we chose contact time for a typical three-credit course at the university. Additionally, some institutions allowed students to apply to pursue self-study courses in lieu of some course credits, usually meeting with a lecturer on an ad hoc basis. These self-study options were also excluded from the averages.

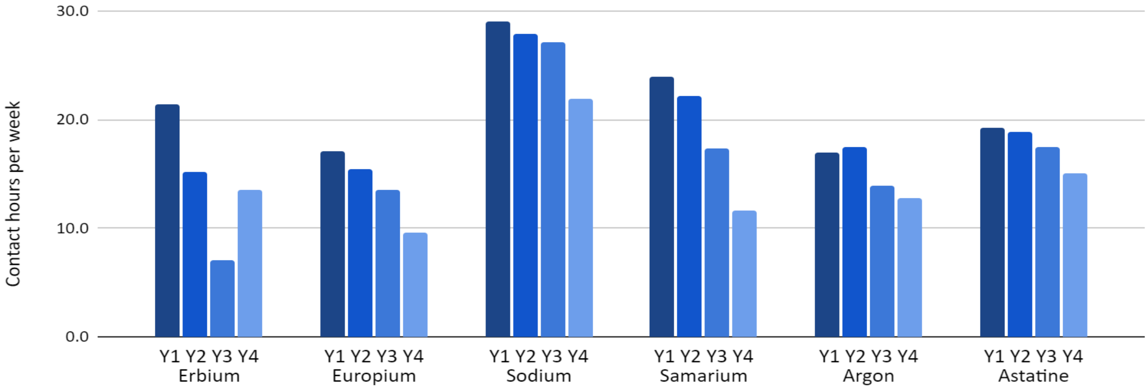

Figure 1: Contact hours per week across the four years of study

Figure 1 shows the variation across the research sites in terms of weekly contact hours. There is a surprising variety of contact time both among institutions and across years of study. The South African universities exhibit the most contact time, particularly in the first and the second year, while the English programs have the lowest overall contact time requirements. The US institutions show the most consistency across the four years. Two institutions (Erbium and Samarium) show a substantial difference in contact time between the initial years of study and later years. This difference is due to the project and dissertation work that students are required to undertake in the later years. Especially at Erbium, the weekly contact time dips quite significantly in the third year as students spend significant time on their dissertations in that year. It is important to note here that a change in weekly contact time does not necessarily indicate a change in the amount of time a student is expected to spend on their studies. All of the programs maintain a reasonably even distribution of expected workload across the curriculum as indicated by course credits, despite the clear differences in contact time. Course credits are usually calculated on the basis of notional hours that a student is expected to spend on the course, and these hours include both the structured contact time and the time a student is expected to spend on the course requirements on their own. All curricula show a general decrease in contact time as the program progresses, likely indicative of a transition to more self-directed learning and project work.

A relatively packed schedule, especially in the initial years of the degree, was highlighted by several students in their first-year interviews. As Nina from Samarium notes:

> *I start at 9h00 with Maths and then I go to my second lecture, which is chemical engineering. After that I go to chemistry and then my final lecture at 12h00 is stats until 13h00. Monday afternoons I have off or we use our time to do project work or practicals in chemical engineering or catch up on any work that you have. Tuesday I have the same morning from 9h00 to 13h00, and then afternoons I have chemical engineering from 2-5pm, which is usually used for the project work, group work. Wednesday I have the same morning again and then I have a Maths tut from 2 to 4pm and then Thursday the same morning and from 2-5pm I have a chemistry prac. Friday is the same morning and then I have chemical engineering again from 2 to 5pm, project work. (Nina, Year 1)*

Similarly, Lawrence from Erbium University highlights that some of his weekdays are very compactly packed with lectures, labs, and tutorials.

> *Monday, we usually have a few lectures, two or three, and then a little bit of a break. Then, we'll have a lab for three hours. Monday is quite busy. Then, Tuesday and Wednesday, we just have lectures. We'll probably have two lectures on both those days. On Tuesday, we also have a tutorial with a personal tutor and we just talk over work that we can set for the week before. Then, Thursday, we have three more lectures and a lab. Then, on Friday, we have a Maths workshop and another lecture. It's quite packed in, especially on Mondays and Thursdays. (Lawrence, Year1)*

It is important to note that Lawrence experiences a day with 5-6 hours of contact time as packed even though this schedule is less demanding than a typical day's schedule for Nina.

A relatively light schedule allows students to engage in self-studies and co- and extra-curricular activities. As Sameer describes how his schedule allows these aspects:

> *Mondays and Wednesdays I have three classes… on Tuesdays I have two classes. I have like an early morning 8:00 AM class and then I have one that's more in the afternoon. Then during then I'll either be working on stuff for those classes or studying for those classes or I'll be working on homework for ... if I have any work due further that week, later that week, then I'll be working on that as well. Thursdays are a bit busier. I have four classes that day and two of them are like ... and one of them is a lab so it's like a three-hour, two-and-a-half hour block I think. Then I also have seminar later that day so those days are usually pretty busy. I'm kind of going between classes the whole day. Then Fridays are pretty light. I only have two classes which like my morning class and my afternoon class. Those days I'll either be working and then I'm also researching under two professors so I'll have like a meeting with the professors that I'm researching under and then kind of go over what I've been working on that week for the research. (Sameer, Argon University, Year 2)*

As can be specifically seen in Sameer’s case, due to a lighter timetable, he is already able to engage in undergraduate research in the second year of the degree. Other students from the two US institutions also note how a lighter timetable means that they spend more time learning the materials outside the class than during the scheduled contact time:

> *Yeah, I definitely feel like there's definitely a lot more time outside of class, just in general. For most of my classes, we meet twice a week, so definitely a lot more time on my own with that kind of material. (Drew, Argon University, Year 2)*

> *I definitely spend more time outside of class than in class because we have classes for three hours per class a week. So I end up spending like fifteen, twenty hours for that one class outside of it.*

> *So definitely more outside of class. (Liliana, Astatine University, Year 2)*

Conversely, the South African students struggle to find time for self study.

> *I think that maybe if they could give us more time to actually go through the things that they are teaching us. I think we would do better. (Tawanda, Sodium University, Year 2)*
>
> *It's a lot of things in a short period of time. That's, like, the measure. Some of the concepts I realise that I could've understood better, but because of time I just tend to rush over things. (Ndodzo, Samarium University, Year 2)*

As can be seen from the student quotes, the weekly contact time significantly influences students' learning experiences. A low contact time gives students ample opportunities to engage in self study, and importantly, create extra-curricular learning avenues for themselves. On the other hand, a relatively high contact time leads to a students' perception of being occupied and not having enough time to study on their own.

Curricular rigidity

Another type of curricular variety is whether and to what extent students can control the direction and breadth of their own studies. The structures of the curriculum that allow students to choose what they will study is most usefully considered at the level of the entire curriculum.

As noted earlier, we refer to curricular rigidity as the fraction of course credits that are required by all students in the program. We distinguish between two aspects affecting curricular rigidity: degree specialisations and elective courses. Elective courses are allocated credits within the curriculum that the student can choose how to fulfil. Some elective credits come from a short list of specified courses chosen to meet particular requirements, such as advanced chemical engineering or science courses. Some fulfil credit requirements in broad categories such as humanities or writing. And some allow the student to select any courses of an appropriate level. We acknowledge that is further agency in the ability of students to influence their day-to-day schedule in terms of the order in which they take different compulsory and elective courses, the way they create their weekly schedule during a particular semester, or the time of the day when they take a particular course. However, that fine-grained analysis is beyond the scope of this paper.

Degree specialisations allow students to select a particular area of chemical engineering (e.g., environmental science or biochemistry) within the program and take a fixed sequence of courses focused on that area. Specialisations are often presented as alternative degree plans or structural choices that are specified within a program.

Although specialisations reduce the curricular rigidity for students by giving them options to take courses from a focused area of their choice, they complicate the understanding of curricular rigidity. Firstly, specialisations, typically chosen by students during the second or the third year of their degree, may require students to take some prerequisites, thereby constraining the freedom of choice. Secondly, prerequisite requirements or specialisation rules often make it difficult for students to change to another specialisation once they start taking courses for a particular specialisation. Thirdly, once a specialisation is chosen, further opportunities for the student to direct their studies can be limited by the structure of the specialisation.

In order to give some measure of course rigidity, we compared the number of credits of elective or specialisation-linked courses to the total number of credits in the program. Where an elective was only offered to students who were pursuing a certain specialisation, it was counted under specialisation; otherwise, it was counted under the elective category. Note that the percentages given are an approximate estimate rather than an absolute value. Table 2 depicts the variations across the six universities in terms of the curricular rigidity in the chemical engineering programs they offer.

Table 2: Variation of curricular rigidity expressed as percentages of course credits

Institution	Specialization	Elective	Combined Choice	Curricular Rigidity
Erbium	0.0%	0.0%	0.0%	100.0%
Europium	0.0%	0.0%	0.0%	100.0%
Sodium	0.0%	0.0%	0.0%	100.0%

Samarium	7.5%	14.3%	21.8%	78.2%
Argon	0.0%	20.3%	20.3%	79.7%
Astatine	18.6%	24.0%	42.6%	57.4%

As can be seen from Table 2, Erbium, Europium, and Sodium, have an entirely rigid curriculum structure without any electives or explicit specialisation options. In contrast, Samarium and Argon each have slightly less than four-fifths of their degree requirements determined by a rigid degree structure; and at Astatine, chemical engineering students can choose to have less than two-thirds of their coursework in common. The variation in rigidity between the two US and the two South African institutions suggest that rigidity may be more determined by institutional culture rather than national context. It would be necessary to use this measure across more institutions in each national context to draw any substantial conclusion on this observation.

The ability to choose courses according to their interests allowed students to explore different disciplines, thereby expanding their knowledge and worldview. For example, Adrian from Argon University notes that taking electives that will help him with his minor in addition to expanding his knowledge base.

> *For my ceiling classes or my electives, I've taken two science-related classes. The first one was Global Science and Technology Policy, and this one I'm taking this semester is Leading Global Sustainability. And I picked this one because it helps me with pursuing a green engineering minor. (Adrian, Argon, Year 1)*

Similarly, Nicholas reflects during the first-year interview how taking a humanities elective is shaping him in a person who is more considerate of diversity and differences.

> *I am very accepting of people. I do realize that [prejudice and discrimination against people] happen and [it is important] to be able to look out for that and to check myself. I think doing gender studies is also helping a lot in this regard. (Nicholas, Samarium, Year 1)*

Ndodzo describes how her elective adds a different dimension to her development as a professional engineer in that she recognizes the importance of planning and executing engineering work in a way that prioritizes the need of the community.

> *It [a Humanities elective course] talks about social infrastructures, infrastructures that are meant to bring communities together. The course is about… discussing and actually exploring how it really would be when you are dealing with projects in the community…. Sometimes you do projects trying to improve people's lives, but that is not their first need. And when they see you guys doing that, they might destroy your work. And then money's down the drain because you didn't communicate with the community to see first what they actually need. (Ndodzo, Samarium, Year 3)*

These student experiences suggest that curricular rigidity can affect students' professional in two significant different ways. First, it can prevent students from pursuing different minors and specializations based on their interests and career aspirations. Second, it can also devoid students an opportunity to explore disciplines other than engineering, which may prevent them to develop a diverse worldview and consider an engineering problem from different perspectives.

First year of the degree

A third way in which the chemical engineering programs under consideration differ from one another was in the design of the first year of study. The first year of the degree varies across the six institutions in two significant ways: 1) admission of the students into the major, 2) exposure of students to the discipline-specific course content, i.e., courses required only of students who are pursuing a chemical engineering degree.

In terms of admission of students into the major, four out of the six programs (Europium, Sodium, Samarium, and Astatine) admit students directly into the chemical engineering degree. At the other two, Erbium and Argon, students join a general engineering program in the first year of the degree. It is only at the end of the first year that they can choose their engineering major based on their interest and performance in the general engineering courses taken in the first year.

In terms of exposure of students to the discipline-specific course content, some engineering programs present a common first year, allowing and sometimes requiring students to learn about different engineering disciplines before choosing a course of study. Others incorporate substantial discipline-specific (i.e., chemical engineering) content from the first year. Table 3 presents these variations in the first-year curricula across the six institutions under study in terms of exposure of students to the discipline-specific content. To provide further insight into the first-year curricular differences, we also provide in Table 3 a categorization of the discipline-specific courses taken by chemical engineering students, identified by the department that offers the course.

Table 3: Structure of the first-year curricula across the six chemical engineering programs

Institution	Erbium	Europium	Sodium	Samarium	Argon	Astatine
Common credit requirements	100.0%	16.7%	96.0%	37.0%	87.9%	100.0% (91.2%)
Discipline-specific credit requirements	0.0%	83.3%	4.0%	63.0%	12.1%	0.0% (8.8%)
Discipline-specific subjects	--	Chemistry, Chemical Engineering	Chemistry	Chemistry, Chemical Engineering, Statistics	Chemistry	-- (Biology)

Note: The first-year curriculum is slightly different at Astatine for students who want to specialize in biotechnology, as indicated by the parenthesis in the table.

As can be seen from Table 3, the six programs present a wide variety of approaches to the first year. For instance, Europium and Samarium introduce a significant number of courses related to chemical engineering in their curricula from the first year of the degree with some courses from the field of chemical engineering itself. Sodium and Argon offer a very small number of courses specific to chemical engineering in the first year; the majority of their first-year courses are common across all engineering disciplines. Students at all four of these universities study a course in chemistry as a discipline-specific course requirement.

Erbium and Astatine have the first year of the degree as entirely common across all engineering disciplines. Common first year courses at the six universities generally include introductory courses in engineering problem solving and design, math, and science. At Astatine, students are given an option to opt for a specialisation in biotechnology during the course of their chemical engineering degree. Those who want to specialise in biotechnology are required to take one-discipline specific course in biology during their first year instead of taking all common first-year courses. Although students are admitted to a general engineering program in the first year at Argon, they are encouraged to take more courses in chemistry if they plan to pursue chemical engineering. It is these chemistry courses that lead to a first-year curriculum at Argon that is not entirely common across all engineering disciplines.

Another point to note here is that a higher common credit requirement in the first year does not necessarily mean a higher curricular rigidity. It is possible that students while pursing the common first-year curriculum have an option to choose electives within the common courses. This is why Astatine with a very high common credit requirement in the first year still has the lowest curricular rigidity.

Further, Table 3 is that the variation within countries is also significant, with dramatically different structures from different institutions within England and South Africa. As with curricular rigidity, further study in each national context would be necessary to determine the influence of national engineering culture on these choices.

The differences in the first-year curricular structures significantly influenced students' experiences in terms of identifying with their major of study. An early exposure to chemical engineering through their specialised first-year courses helped students better relate to their discipline. For example, as Rabeea from Europium University notes:

> *I have for certain lab experiments, for example, fluid flow which is another subtopic of one of my modules, heat transfer and fluid*

> *flow. Yes, so maybe because I’ve done the lecture now and I’ve done the lab practical for it now and I was interested, so yes, maybe I would want to go and see how other big chemical engineering companies use it in action or how it actually worked in society. (Year 1)*

As evident in this quote, an early exposure to both lab and theory work in chemical engineering ignited her interest in the discipline. Similarly, Nisha from Samarium University highlights how she has already started to learn about the work of a chemical engineer through her first-year chemical engineering course.

> *In our chemical engineering course… we have guest speakers who come back and tell us what they do and what opportunities are out there and what their careers were like; so we learn from that. We are also doing this assignment… to find a chemical engineer and correspond with them through email about what their job is like. [Through these activities] you get a better idea of what is expected of us [when we graduate]. [Nisha, Year 1, Samarium]*

Thus, a more discipline-focused first year has helped both Rabeea and Nisha gain a better understanding of chemical engineering. Conversely, when students did not find their first year directly related to their major of study, they not only struggled to develop an understating of the discipline but also did not find the use of the courses.

> *The first year is all common for all engineers. It’s just something you’re learning things and you think, “Okay, I don’t really think I’m going to use this in my degree.” (Lucas, Erbium, Year 1)*

> *I don't think my Intro to Engineering class was a very useful class. I don't think it really taught me anything. I think that class could be more specialised towards each of the different engineering disciplines. (Marley, Astatine, Year 1)*

While a common first year posed difficulties for students in findings the relevance of the courses they studied, it also afforded some advantages. Specifically, a common first year gave students an option to change majors in case they did not find chemical engineering to be a good fit. As Luke from Erbium University notes:

> *I don't like it [my common first-year electronics course], and I don't see when I am going to use it. I will be surprised if I get over 60% in the final exam for electronics. But it has also benefited me because if I had gone straight into nuclear [chemical] engineering, I doubt I would be able to change [my major if I didn't like it]. It is a mixture. But I have benefited from it so I shouldn't complain too much. (Year 1)*

The student experiences depict that a discipline-specific first year can play an important role in helping students learn about the professional practice, which may lead to an increased interest in the discipline. Conversely, a first-year curriculum more generic in nature may feel a bit irrelevant to students and also prevent them from seeing the value in what they are studying.

Discussion and Conclusion

The findings show that there is a lot of variation in the ways in which chemical engineering courses are structured not only across countries but also within the same national context in terms of the three parameters: contact hours, curricular rigidity, and first year of the degree. In Bernsteinian terms, this shows that the manner in which the recontextualization of the disciplinary knowledge into the curriculum is done may be divergent, but it can still be perceived to fulfil a common goal. In this paper we have shown the different ways chemical engineering curricula can be structured while meeting the accreditation requirements of the Washington Accord. Thus, our findings add to the existing literature (e.g., Downey et al., 2006; Klassen & Sá, 2020) on how engineering curricula differ from one another based on the local and the national requirements while maintaining the accreditation goals. However, the unique contribution of our work is the exploration of curricular differences at the micro level that concerns students' ability to attend classes and choose electives and degree specializations. These findings further confirm that the global accreditation requirements provide flexibility in terms of curricular specifications (Prados et al., 2005).

The variations in the day-to-day structuring of the curriculum may have significant implications for the formation of students as engineers. For example, the degree to which the first-year courses overlap with courses in other engineering programs (most pronounced at Erbium) determines how easy it is for a student to switch into another engineering program before the commencement of the second year, as also highlighted by Luke. Where the first-year requirements are very similar between disciplines, students are more likely to be able to change to another discipline without substantial delays in their overall degree-completion time. The same flexibility is afforded to students who enter a general engineering program and choose chemical engineering as their major only at the beginning of the second year, a feature of curricula at Erbium and Argon. However, the advantage of this capacity to switch between engineering programs is balanced with the advantage of developing a clear identity for chemical engineers early in the program. At Samarium, for example, there are several elements in the first year which are clearly aimed at community building and early identification with the discipline and the profession. Through an early exposure to the discipline through these curricular elements, students start to build an understanding of the discipline sooner than later, which has implications for the formation of professional identity and student retention in the major (Mann et al., 2009; Matusovich et al., 2010).

The possibility of different degree streams in terms of specialisations, which are present at Astatine and Samarium, allow for the possibility for students to follow a path that inclines more towards their particular interests. However, the retention of a substantial commonality between different streams suggests that there may still be a strong coherency in the training of the students who come through different streams. Along similar lines, the ability to choose elective courses (often across a diverse range of academic disciplines), present at Samarium, Argon, and Astatine, allows students to study and get exposed to a diverse range of subjects. This allows students to not only pursue different interests leading to the development of diverse skills but also develop alternate worldviews. A curriculum that offers alternatives for technical coursework has shown to also enable students to shift their majors and sometimes to leave engineering (Lichtenstein et al., 2009). An exploration of diverse interests and exposure to different worldviews is also enabled by a curriculum that has a relatively low number of weekly contact hours. Fewer weekly contact hours allow students more flexibility to structure their day-to-day schedule, thus enabling them to engage in extra-curricular and co-curricular activities.

Given that all of these institutions have accredited chemical engineering degrees, it is evident that there are multiple ways to achieve the outcomes determined by the Washington Accord. The substantial variation in structure presented herein should give engineering educators and institutions pause for thought. Just because a course has been currently structured in a particular way does not mean that it is necessarily the best way. For example, are the relatively high contact times found at Sodium actually necessary? Likewise, is the rigidity of curricula at Erbium, Europium and Sodium essential? The national academic context does indeed determine some of these salient features of the engineering curriculum (Case et al., 2016), but our analysis also provides examples of significant differences between the universities situated within the same national context.

References

ABET. (2002). Criteria for accrediting engineering programs–effective for evaluations during the 2003–2004 accreditation cycle. ABET.

Adelman, C. (2009). The Bologna Process for US Eyes: Re-learning Higher Education in the Age of Convergence. Institute for Higher Education Policy.

Ashwin, P. (2019, April 13). Higher education is about transformation. University World News. https://www.universityworldnews.com/post.php?story=20190408084550435&fbclid=IwAR2xSej6jo_tGvXiZT6DtTW0nklRDan4mMA9ffgepgLgyLZt64WDb0CFpD0

Bernstein, B. (2000). Pedagogy, symbolic control, and identity: Theory, research, critique. Rowman & Littlefield.

Buyurgan, N., & Kiassat, C. (2017). Developing a new industrial engineering curriculum using a systems engineering approach. European Journal of Engineering Education, 42(6), 1263–1276. https://doi.org/10.1080/03043797.2017.1287665

Case, J. M. (2017). The historical evolution of engineering degrees: Competing stakeholders, contestation over ideas, and coherence across national borders. European Journal of Engineering Education, 42(6), 974–986. https://doi.org/10.1080/03043797.2016.1238446

Case, J. M., Fraser, D. M., Kumar, A., & Itika, A. (2016). The significance of context for curriculum development in engineering education: A case study across three African countries. European Journal of Engineering Education, 41(3), 279–292. https://doi.org/10.1080/03043797.2015.1056103

Centre for Economics and Business Research. (2016). Engineering and economic growth: A global view. Royal Academy of Engineering.

Chandrasekaran, S., Stojcevski, A., Littlefair, G., & Joordens, M. (2013). Accreditation inspired project oriented design based learning curriculum for engineering education. IETEC 2013: Enhancing Global Engineering and Technology Education: Meeting the Future: Proceedings of the 2nd International Engineering and Technology Education Conference 2013, 1–11.

Council on Higher Education. (2013). A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure. In Report of the Task Team on Undergraduate Curriculum Structure. Council on Higher education Pretoria.

Downey, G. L., Lucena, J. C., Moskal, B. M., Parkhurst, R., Bigley, T., Hays, C., Jesiek, B. K., Kelly, L., Miller, J., Ruff, S., Lehr, J. L., & Nichols-Belo, A. (2006). The globally competent engineer: Working effectively with people who define problems differently. Journal of Engineering Education, 95(2), 107–122. https://doi.org/10.1002/j.2168-9830.2006.tb00883.x

Graham, R. (2012). The one less traveled by: The road to lasting systemic change in engineering education. Journal of Engineering Education, 101(4), 596.

Graham, R. (2017). The global state of the art in engineering education. Massachusetts Institute of Technology (MIT) Report, Massachusetts, USA.

Jamieson, L. H., & Lohmann, J. R. (2012). Innovation with impact: Creating a culture for scholarly and systematic innovation in engineering education. American Society of Engineering Educators.

Jawitz, J., Marais, N., & Hanrahan, H. (2001). Using accreditation to drive curriculum development in engineering. Australasian Journal of Engineering Education, 9(2), 137–146.

Klassen, M., & Sá, C. (2020). Do global norms matter? The new logics of engineering accreditation in Canadian universities. Higher Education, 79(1), 159–174. https://doi.org/10.1007/s10734-019-00403-6

Kotys-Schwartz, D., Besterfield-Sacre, M., & Shuman, L. (2011). Informal learning in engineering education: Where we are—Where we need to go. 2011 Frontiers in Education Conference (FIE), T4J-1.

Lichtenstein, G., Loshbaugh, H. G., Claar, B., Chen, H. L., Jackson, K., & Sheppard, S. D. (2009). An engineering major does not (necessarily) an engineer make: Career decision making among undergraduate engineering majors. Journal of Engineering Education, 98(3), 227–234. https://doi.org/10.1002/j.2168-9830.2009.tb01021.x

Lucena, J., Downey, G., Jesiek, B., & Elber, S. (2008). Competencies beyond countries: The re-organization of engineering education in the United States, Europe, and Latin America. Journal of Engineering Education, 97(4), 433–447. https://doi.org/10.1002/j.2168-9830.2008.tb00991.x

Mann, L., Howard, P., Nouwens, F., & Martin, F. (2009). Influences on the development of students' professional identity as an engineer. Proceedings of the Research in Engineering Education Symposium 2009.

Matthews, P., Ryan-Collins, L., Wells, J., Sillem, H., & Wright, H. (2012). Briefing: Engineers for Africa: Identifying engineering capacity needs in sub-Saharan Africa. Proceedings of the Institution of Civil Engineers, 165(4), 187–188.

Matusovich, H. M., Streveler, R. A., & Miller, R. L. (2010). Why do students choose engineering? A qualitative, longitudinal investigation of students' motivational values. Journal of Engineering Education, 99(4), 289–303. https://doi.org/10.1002/j.2168-9830.2010.tb01064.x

Matusovich, H., Streveler, R., Loshbaugh, H., Miller, R., & Olds, B. (2008). Will I Succeed in engineering? Using expectancy value theory in a longitudinal investigation of students' beliefs. 2008 Annual Conference & Exposition, 13–1403.

Meah, K., Hake, D., & Wilkerson, S. D. (2020). A multidisciplinary capstone design project to satisfy abet student outcomes. Education Research International, 2020.

Morgan, R., & Ion, S. (2014). The universe of engineering: A call to action. Royal Academy of Engineering.

Prados, J. W., Peterson, G. D., & Lattuca, L. R. (2005). Quality assurance of engineering education through accreditation: The impact of Engineering Criteria 2000 and its global influence. Journal of Engineering Education, 94(1), 165–184. https://doi.org/10.1002/j.2168-9830.2005.tb00836.x

Seely, B. E. (1999). The Other Re-engineering of Engineering Education, 1900–1965. Journal of Engineering Education, 88(3), 285–294.

Stevens, R., O'Connor, K., & Garrison, L. (2005). Engineering student identities and the navigation of the undergraduate curriculum. 2005 Annual Conference, 10–558.

Stevens, R., O'connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. Journal of Engineering Education, 97(3), 355–368. https://doi.org/10.1002/j.2168-9830.2008.tb00984.x

van Antwerpen, F. (1980). The origins of chemical engineering. In W. Furter (Ed.), History of Chemical Engineering (pp. 1–14). ACS Publications.

Voronov, R. S., Basuray, S., Obuskovic, G., Simon, L., Barat, R. B., & Bilgili, E. (2017). Statistical analysis of undergraduate chemical engineering curricula of United States of America universities: Trends and observations. Education for Chemical Engineers, 20, 1–10. https://doi.org/10.1016/j.ece.2017.04.002

Washington Accord. (2020). Washington Accord: Signatories. https://www.ieagreements.org/accords/washington/signatories/

Yao, Z., Yan, T., & Hu, M. (2022). Comparison of undergraduate chemical engineering curricula between China and America Universities based on statistical analysis. Education for Chemical Engineers, 38, 55–59. https://doi.org/10.1016/j.ece.2021.10.003