

Projectstatus Universitaire chemicus van de toekomst

HCA werkgroep Raad vd Scheikunde, 20 maart 2025

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Inleiding en probleemstelling

De chemie en de chemische sector staan voor grote uitdagingen als gevolg van maatschappelijke, wetenschappelijke en technologische ontwikkelingen. Denk hierbij aan klimaatverandering, grondstoffen- en energietransitie, circulaire economie en de opkomst van A.I.

Om de benodigde transities mogelijk te maken zijn goed opgeleide universitaire chemici nodig. Echter, wat is het profiel van deze chemicus? Voldoet het huidige profiel of zijn wijzigingen noodzakelijk? En, zo ja, welke nieuwe onderwijsprogramma's passen daar bij? Deze vraagstellingen zijn in 2021 opgepakt door de HCA werkgroep "Universitaire chemicus van de toekomst". In deze notitie wordt de projectstatus weergegeven. De werkgroep rapporteert aan de Raad van de Scheikunde, en aan de BSc- MSc onderwijsdirecteuren van de chemische faculteiten.

Binnen de universitaire community zijn er zorgen over de dalende studentenaantallen, m.n. bij de traditionele universitaire chemieopleidingen. Over dit onderwerp is regelmatig (2x per jaar) overleg tussen C3 en de scheikunde voorlichters van de verschillende universiteiten. Het aantrekkelijk maken/ houden van chemische opleidingen is echter een aspect dat mede vanuit de onderwijsdirecteuren kan worden opgepakt in het kader van de "Chemicus van de Toekomst".

Aanpak

In de periode 2021-2024 heeft de Human Capital Werkgroep van de Raad voor de Scheikunde de volgende activiteiten uitgevoerd:

1. Analyse "Frame of Reference" van onderwijsaudit van scheikunde opleidingen in 2018 (Appendix 1)
2. Identificatie van uitdagingen door gesprekken met opleidingsdirecteuren, onderzoekers en industriële vertegenwoordigers (2021-2023)
3. Discussie met 150 PI's over human capital tijdens CHAINS congres (2022)
4. Onderzoek naar human capital thema's door de PI's van Nextgenchem (2022)
5. Afstemming met beta-decanen (2023)
6. Twee nationale bijeenkomsten met scheikunde (BSc- en MSc-) opleidingsdirecteuren van alle Nederlandse universiteiten (2024, zie Appendix 2)
7. Afstemming met het landelijke overleg van scheikunde voorlichters (2024)
8. CHAT GPT "consultatie" over de chemicus van de toekomst (2024, zie Appendix 3)
9. Formulering van conclusies en aanbevelingen (deze notitie)

Resultaten HCA werkgroep

De activiteiten en bijeenkomsten van de werkgroep hebben belangrijke inzichten opgeleverd. Hieronder volgt een overzicht van de belangrijkste gespreksonderwerpen, conclusies en aanbevelingen.

1. De definitie van scheikunde/ chemie

- **Conclusie:** Er is sprake van een brede range van chemie gerelateerde opleidingen in Nederland. Bij de universitaire chemie onderwijsaudit in 2018/2019 is de chemie definitie uit het sectorplan Natuur/scheikunde uit 2016 gevolgd: als een opleiding minstens 50% moleculaire/ chemie onderdelen bevat dan wordt de opleiding als “chemisch” gezien. Chemische BSc- en MSc opleidingen vinden hun aansluiting binnen een of meerdere van een viertal chemische domeinen: Chemistry, Chemical- and Bio Engineering, Molecular Life Sciences en Pharmaceutical Sciences, zie ook blz 7 voor een grafische weergave. In het onderwijs-arbeidsmarkt van ChemistryNL is een uitgebreid overzicht te vinden van alle chemie gerelateerde opleidingen inclusief studenten- en diploma aantallen en statistieken over vacatures en arbeidsmarkten.
- **Aanbeveling:** Bespreek de ontwikkelingen en trends minstens 1x per jaar met alle universiteiten, inclusief karakteristieken van de verschillende opleidingen zoals bijv. fundamentele chemie vs. chemie voor applicatie gebieden.

2. De bekendheid van chemische opleidingen

- **Conclusie:** Chemie is essentieel voor het aanpakken van de maatschappelijke, wereldwijde uitdagingen. Dit is inmiddels standaard gedachtengoed in het scheikunde curriculum op middelbare scholen. De bekendheid en aantrekkelijkheid van chemische BSc vervolgoopleidingen kan echter nog naar een hoger niveau worden gebracht. Het ontbreekt aan een makkelijk(er) overzicht van al deze opleidingen, en hun verschillen. Ook is er geen breed omarmd “narratief” waarin wordt ingegaan op de mogelijke rollen van chemici, en op arbeidsmarkten/ toepassingsgebieden.
- **Aanbeveling:** Creëer (bijv als project binnen de eerste graads chemieopleidingen) een aantrekkelijk narratief dat de positionering van chemie opleidingen aan Nederlandse universiteiten beschrijft, alsmede de rol(len) van chemici en bestemmingen op de arbeidsmarkt. Dit kan helpen om de bekendheid en het imago van chemische opleidingen te verbeteren en meer studenten aan te trekken.

3. Verbinding tussen opleidingen en werkveld

- **Conclusie:** Chemici komen terecht in veel verschillende werkvelden, zie ook het eerder genoemde ChemistryNL dashboard en Appendix 2. Het is belangrijk dat universiteiten een goed, actueel beeld hebben over wat het werkveld vraagt, zodat BSc programma's en Master tracks bij de tijd kunnen worden gehouden.
- **Aanbeveling:** Organiseer naast de universitaire werkveld adviescommissies ook een *nationale* werkveldadvies commissie om trends onderling te bespreken, alsmede de opties en drivers van curriculum vernieuwing.

4. Vernieuwing van het chemie curriculum

- **Conclusie:** In het chemie curriculum van de toekomst blijft het aanbieden van goede fundamentele, moleculaire kernvakken cruciaal. Nieuwe aandachtsgebieden zoals datawetenschappen, AI en systeemdenken moeten echter ook een plek krijgen.
- **Aanbeveling:** Deel als universiteiten de visies op de “eindtermen” van de nieuwe vakken alsmede de wijze waarop die eindtermen door de student behaald dienen te worden. Denk na over integratie van de “chemische” vakken met de “nieuwe vakken” om overladenheid van het curriculum te voorkomen.

5. Gedragsvaardigheden van de Chemicus van de Toekomst

- **Conclusie:** Naast technische kennis blijven interdisciplinaire samenwerking, communicatie en ethisch besef essentieel. Deze onderwerpen hebben in principe binnen de huidige curriculum al hun plek. Wat echter nieuw is, is de veel hogere “kloksnelheid” van chemische ontwikkelingen, en de toegenomen data hoeveelheid.
- **Aanbeveling:** Introduceer binnen het scheikunde curriculum ook een agility/ innovatie element, b.v. door gebruik van challenges en learning communities, waarbij praktijkgerichte cases worden ingebracht vanuit bedrijven.

6. Samenwerking tussen universiteiten

- **Conclusie:** Curriculumontwikkeling van scheikundeopleidingen vindt plaats zonder (veel) afstemming tussen universiteiten onderling
- **Aanbeveling:** Plan structureel overleg tussen de onderwijsdirecteuren van universiteiten onderling om gemeenschappelijke leerdoelen voor chemici te definiëren en best practices in curriculumontwikkeling te delen. Dit overleg kan ook dienen om de volgende onderwijsauditronde, die is voorzien vanaf 2026, voor te bereiden.

Conclusies en discussie

In de bijeenkomsten met de BSc- en MSc onderwijsdirecteuren is vastgesteld dat de doorontwikkeling van (presentatie en inhoud van) scheikunde opleidingen nuttig en nodig is. Een structureel, nationaal gecoördineerd overleg, georganiseerd door de onderwijsdirecteuren kan hier vorm en inhoud aan geven. Voorgesteld wordt om deze nationale aanpak in 2025 vorm te geven a.h.v. de discussie onderwerpen zoals hierboven geschetst, en daarbij ook gebruik te maken van het inhoudelijke materiaal dat in onderstaande referenties staat beschreven. Leden van de huidige HCA werkgroep van de Raad van de Scheikunde zijn gaarne bereid om support te verlenen bij dit proces.

Referenties

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9. Website Royal Society of Chemistry: Future Workforce and educational pathways (2024).
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APPENDIX 1

FRAME OF REFERENCE CHEMICAL SCIENCES IN THE NETHERLANDS

(Augustus 2017, Peter Hamersma/ TUD en Wilko van Loon/ WUR)

Introduction

The domain of chemical sciences in the Netherlands covers today not only the field of chemistry and chemical engineering, but also the domains between chemistry, biology and engineering represented by the molecular life sciences, life science and technology, biomolecular sciences and pharmaceutical sciences. To cover the domain of the chemical sciences 17 academic 3-years bachelor programmes and 18 academic 2-years master programmes are offered by the Dutch universities (see Table 1). These academic programmes result in respectively a bachelor of science (BSc) and master of science (MSc) qualification.

Table 1: Overview of all participating programmes.

Name of the programme*	Institution	Brin-ISAT CROHO 2016
B Bio-Farmaceutische Wetenschappen	Universiteit Leiden	21PB-50207
B Farmaceutische Wetenschappen	Vrije Universiteit Amsterdam	21PL-56989
B Life Science and Technology (joint degree)	Technische Universiteit Delft	21PF-55010
	Universiteit Leiden	21PB-55010
B Moleculaire Levenswetenschappen	Radboud Universiteit Nijmegen	21PM-59304
	Wageningen University	21PI-59304
B Molecular Science and Technology (joint degree)	Technische Universiteit Delft	21PF-55009
	Universiteit Leiden	21PB-55009
B Scheikunde	Radboud Universiteit Nijmegen	21PM-56857
	Rijksuniversiteit Groningen	21PC-56857
	Universiteit Utrecht	21PD-56857
	Universiteit van Amsterdam	21PK-56857
	Vrije Universiteit Amsterdam	21PL-56857
B Scheikundige Technologie	Rijksuniversiteit Groningen	21PC-56960
	Technische Universiteit Eindhoven	21PG-56960
	Universiteit Twente	21PH-56960
B Science	Radboud Universiteit Nijmegen	21PM-56948
M Biomolecular Sciences	Vrije Universiteit Amsterdam	21PL-60616
M Bio-Pharmaceutical Sciences	Universiteit Leiden	21PB-60207
M Chemical Engineering	Rijksuniversiteit Groningen	21PC-60437
	Technische Universiteit Delft	21PF-60437
	Technische Universiteit Eindhoven	21PG-60437
	Universiteit Twente	21PH-60437
M Chemische Wetenschappen	Universiteit Utrecht	21PD-60706
M Chemistry	Radboud Universiteit Nijmegen	21PM-66857
	Rijksuniversiteit Groningen	21PC-66857
	Universiteit Leiden	21PB-66857
	Universiteit van Amsterdam	21PK-66857

	Vrije Universiteit Amsterdam	21PL-66857
M Drug Discovery and Safety	Vrije Universiteit Amsterdam	21PL-66989
M Life Science and Technology	Technische Universiteit Delft	21PF-66286
	Universiteit Leiden	21PB-66286
M Molecular Life Sciences	Radboud Universiteit Nijmegen	21PM-60303
	Wageningen University	21PI-60303
M Science	Radboud Universiteit Nijmegen	21PM-66982

* B = 3-years BSc; M = 2-years MSc ; by law an academic year covers 60 credits or 1680 hours of student study work load.

In this document the framework described by the chemical and bio-based industries as well as the teaching-learning environment, Dublin descriptors and domain specific learning outcomes of the bachelor and master academic programmes in the broad “chemistry” domain are described.

Curriculum requirements of Dutch chemical academics from an industry perspective

By Onno Vreede, The Association of the Dutch Chemical Industry (VNCI)

The Dutch chemistry academic of today, adopting for a career in the chemical/ process industry, finds himself in a much more vigorous environment after his studies than 10-20 years ago.

Since a few years, the European chemical industry is facing heavy global competition from other chemical production regions that benefit from cheap shale gas (U.S.) and/ or lower work force costs (China). In order to increase labour productivity, new digital “4.0” technologies need to be implemented to keep the European chemical industry “smart” and competitive. Aging production assets put an additional challenge on keeping production processes safe and secure for people and environment.

Next to optimization and upgrading of current “fossil fuel based” production facilities the need for transition towards a circular economy is becoming more and more evident every day. Both from an energy-resource depletion perspective as well as from a climate-pollution perspective it is clear that new technologies and new molecules are needed to sustainably meet the needs of a strongly growing population with respect to food, energy, medicines and materials. For this, the chemical industry has a major role to play. Development and scale-up of new technologies such as bio-based, electrification and recycling are needed to replace the current fossil fuel based production system in the next few decades. European targets are set at 80-95% reduction of CO₂ in 2050. Finding business models for companies to make the transition is still a big challenge, however.

Based upon the above it can be concluded that many challenges lay ahead where chemical academics are to play a crucial role. With respect to the curriculum requirements of Dutch academics in Chemical Sciences, like Applied Sciences, Chemistry and/or Chemical Engineering, it can be said that knowledge and demonstrated skills in “pure” academic, chemical disciplines remain important. In addition to that, however:

1. Direct industry experiences of students remain crucial and should be intensified, at least for those students who wish an industrial career. A “major” traineeship or internship should be one of the opportunities. In the education more attention should be given to (the leadership aspects of) safety, health and environment in the field of chemical sciences.
2. Training the “speed-of-innovation” should be a clear element of the education, through “challenges”, boot camps and a like, in multidisciplinary settings where available information is limited and competences such as teamwork, initiative and entrepreneurship are trained.
3. Knowledge and skills in the area of application of new smart technologies in the chemical industry should be a clear part of the education.

Teaching-learning environment

In The Netherlands “the chemical sciences” covers four different sub-domains: chemistry, chemical and bio-engineering, molecular life sciences and the pharmaceutical sciences. Not all study programmes fit completely within one subdomain as they might find their niche partly in two subdomains. As an example the B Molecular Life Sciences (Wageningen University) combines chemistry with molecular life sciences, whereas the joint programme M Life Science and Technology (Technical University Delft and Leiden University) combines chemical engineering with molecular life sciences and the (see Figure 1).

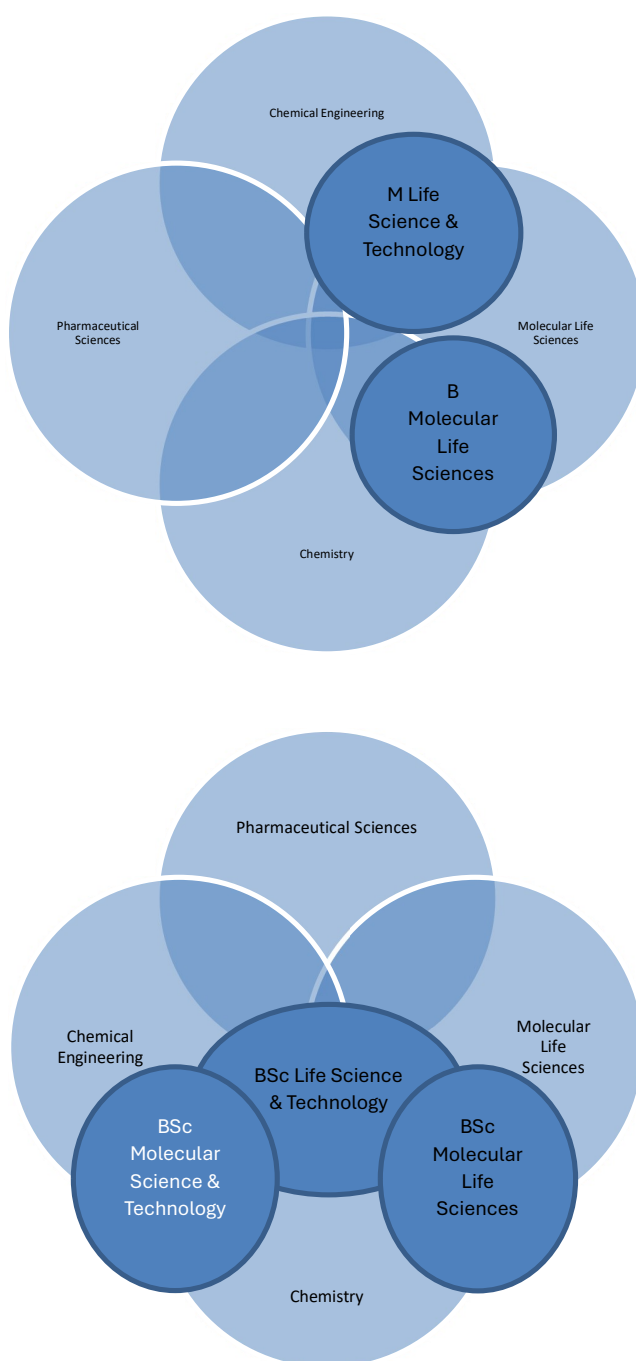


Figure 1. Example of study programme positions within the four chemical sciences sub-domains.

The general competences and learning outcomes described here refer to the academic university system for science and engineering courses in The Netherlands. Generally, the 3-year bachelor programmes consists of major of 150 credits and a minor programme of 30 credits. Some bachelor programmes offer specialisations tracks within the major. The bachelor programme will be finalised by a thesis project and results in a Bachelor of Science qualification.

Graduates who have obtained their bachelor of science degree usually continue with a 2-year master programme. Generally in the same discipline although an increasing number of students choose another master programme of their interest. In the disciplinary master a further specialisation takes place. It is important to notice that in The Netherlands science and engineering students normally complete their master study with a major thesis project resulting in a Master of Science qualification. Most master programmes offer extra courses for students who do not fulfil the entrance requirements, for example students of Universities of Applied Sciences. The programmes for these students are pre-described by a MSc Programme Admission Committee. For more talented students many institutions offer honours programmes to stimulate these students to do more than the standard curricula offered.

The Dublin descriptors

The Dublin Descriptors are the cycle descriptors (or "level descriptors") presented in 2003 and adopted in 2005 as the Qualifications Framework of the European Higher Education Area. They offer generic statements of typical expectations of achievements and abilities associated with awards that represent the end of each of a (Bologna) cycle or level. The descriptors are phrased in terms of competence levels, not learning outcomes, and they enable to distinguish in a broad and general manner between the different cycles. A level descriptor includes the following five components:

- Knowledge and understanding
- Applying knowledge and understanding
- Making judgements
- Communication
- Lifelong learning skills

Descriptors	Bachelor (3-years ; 180 ECTS credits ; first cycle ; EQF level 6)	Master (2-years ; 120 ECTS credits ; second cycle ; EQF level 7)
	Qualifications that signify completion of the bachelor degree are awarded to students who:	Qualifications that signify completion of the master degree are awarded to students who:
Knowledge and understanding	have demonstrated knowledge and understanding in a field of study that builds upon their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study	have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with the first cycle, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context
Applying knowledge and understanding	can apply their knowledge and understanding in a manner that indicates a professional approach to their work, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of study	can apply their knowledge and understanding, and problem solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study
Making judgements	have the ability to gather and interpret relevant data (usually within their field of	have the ability to integrate knowledge and handle complexity, and formulate judgements

	study) to inform judgements that include reflection on relevant social, scientific or ethical issues	with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgements
Communication	can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences	can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously
Lifelong learning skills	have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy	have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous

*We distinguish three cycles, i.e. 1st and 2nd cycle comparable with bachelor and master and a 3rd cycle referring to PhD and or other post-master courses. The abbreviation EQF refers to the European Qualifications Framework (<https://ec.europa.eu/ploteus/en/content/descriptors-page>)

Domain specific learning outcomes of bachelor programmes

Content

In this section the Dublin Descriptors are “translated” into more domain specific learning outcomes of the different fields of the domain of chemical sciences. Each bachelor programme contains a core programme, a minor programme, optional courses and a bachelor thesis work.

The Bachelor Thesis

The academic goal of the Bachelor degree in the chemical sciences is to give undergraduates an initial domain specific research experience. The intention is the graduate will successfully complete an individual research project. This is important not only for those going on to do higher degrees, but also for those leaving the system with a first degree, for whom it is vital that they have personal first-hand experience of what research is about. An industrial placement may be considered a valid alternative to a Bachelor Thesis; such placements should be organised in such a way that their outcomes are clearly documented and that they can be given credits. Thus the Bachelor Thesis project should normally carry at least 15 credits. The Thesis will be written in Dutch or English prescribed by the institution and defended according to the rules of the institution. The supervision (and assessment) of the Bachelor thesis project must be transparent.

Distribution of credits

Each individual institution will of course make its own decision as to the distribution of credits between compulsory, semi-optional and elective modules. It will however be necessary to define a "core" in the form of a recommended minimum number of credits for a number of courses, which are essential for the programme involved. For example, most core programme contains basics of the chemistry domain. This "core" should neither be too large nor too small, and a volume of 50% of the total number of credits, i.e. 90 out of 180, seems a good compromise in view of the different philosophies present in Europe.

In summary most bachelor programmes have the following global distribution of credits:

- ≥ 90 credits are allocated to the core,
- ≥ 15 credits to the semi-optional modules.
- ≥ 15 credits to the Bachelor Thesis project
- The remaining 60 credits (30 of which may come from modules not dealing with chemistry, mathematics, physics or biology) are freely allocable.

CHEMISTRY (BSc)

While institutions should be encouraged to break down the traditional barriers between the chemical sub-disciplines, it is realised that this process will not always be rapid. Thus the traditional classification is retained in what follows. As a reference for the field of chemistry the European Chemistry Thematic Network Association (ECTN) is taken (<http://www.expe.ectn-assoc.org/>).

Compulsory chemistry modules (“the core”) will deal with the main sub-disciplines:

- Analytical chemistry
- Inorganic chemistry
- Organic chemistry
- Physical chemistry
- Biological chemistry

Depending on the staff structure of the department, semi-optional modules will deal with sub-disciplines such as:

- Computational chemistry
- Chemical engineering
- Macromolecular chemistry
- Biochemistry

Depending on the university and department the 30 credits freely allocable are often offered as a minor and 30 credits are offered in related and/or overlapping fields. Examples are courses in material sciences, biochemical engineering or in combinations of the domain as illustrated previous in figure 1.

Bachelor	Chemistry
Knowledge and understanding	- Major aspects of chemical terminology, nomenclature, conventions and units - The major types of chemical reaction and the main characteristics associated with them - The principles and procedures used in chemical analysis and the characterisation of chemical compounds - The principal techniques of structural investigations, including spectroscopy - The characteristics of the different states of matter and the theories used to describe them. - The principles of thermodynamics and their applications to chemistry - The principles of quantum mechanics and their application to the description of the structure and properties of atoms and molecules - The kinetics of chemical change, including catalysis; the mechanistic interpretation of chemical reactions - The characteristic properties of elements and their compounds, including group relationships and trends within the Periodic Table - The structural features of chemical elements and their compounds, including stereochemistry - The properties of aliphatic, aromatic, heterocyclic and organometallic compounds - The nature and behaviour of functional groups in organic molecules - Major synthetic pathways in organic chemistry, involving functional group interconversions and carbon-carbon and carbon-heteroatom bond formation - The relation between bulk properties and the properties of individual atoms and molecules, including macromolecules (both natural and man-made), polymers and other related materials

	- The structure and reactivity of important classes of biomolecules and the chemistry of important biological processes.
Applying knowledge and understanding	- The capacity to apply knowledge in practice, in particular problem-solving competences, relating to both qualitative and quantitative information - Numeracy and calculation skills, including such aspects as error analysis, order-of-magnitude estimations, and correct use of units. - Information-management competences, in relation to primary and secondary information sources, including information retrieval through on-line computer searches. - Information-technology skills such as word-processing and spreadsheet use, data-logging and storage, subject-related use of the Internet. - Skills in planning and time management.
Making judgements	- Ability to analyse material and synthesise concepts. - Ability to include aspects of safety and environment, ethical, societal and economic consequences of (bio)chemical, and technological changes in the design of products - The capacity to adapt to new situations and to make decisions
Communication	- Interpersonal skills, relating to the ability to interact with other people and to engage in team-working. - Communication competences, covering both written and oral communication, in one of the major European languages (English, German, Italian, French, Spanish) as well as in the language of the home country
Lifelong learning skills	- Study competences needed for continuing professional development. These will include in particular the ability to work autonomously - Ethical commitment

CHEMICAL ENGINEERING (BSc)

To ensure the proper common content and proper levels of the different first and second cycle degrees, the European Federation of Chemical Engineers (http://efce.info/Bologna_Recommendation.html) recommends minimum requirements for certain subjects and topics (e.g. mathematics and reaction engineering) that form the core curriculum for the each cycle. Although the first cycle ("bachelor") core curriculum is more detailed than the second cycle ("master") programme, there is still much of the total study left (one academic year) to give the institutions the opportunity to implement their own specialism and/or new development in the field of chemical engineering. For the second cycle the recommendations are very general, making it easy to give a broad range of different orientations within and between institutions while meeting the general outcomes.

A bachelor programme in Chemical Engineering covers the following compulsory modules:

- Fundamentals of science and natural sciences: mathematics, physics, chemistry, biology
- Chemical Engineering fundamentals: material and energy balances, thermodynamics, fluid dynamics, heat and mass transfer, separations, chemical reaction engineering, biomolecular and biological engineering
- Chemical Engineering applications: basic product engineering, safety, health and environment, process analytical techniques, design
- Non-technical subjects: for example economics or management
- Chemical engineering sciences or natural sciences according to the main emphasis of the degree course of the university, like material sciences and biochemical engineering subjects.

Typically, a first cycle ("bachelor's") degree course will contain 20-30 % science courses, 30-50 % engineering courses, and up to 10 % non-technical topics, leaving one third to deeper coverage of some of these topics and to other topics.

Bachelor	Chemical Engineering
Knowledge and understanding	- have a knowledge of relevant basic sciences (mathematics, chemistry, molecular biology, physics) to help understand, describe and deal with chemical engineering phenomena - understand the basic principles underlying chemical engineering: a. mass, energy, and momentum balances b. separation processes and equilibrium c. rate processes (chemical reaction, mass, heat, momentum transfer) - understand the basic concepts of process control and materials sciences - understand the principles underlying methods of process/product measurements - have a knowledge of relevant literature and data sources - have a basic understanding of health, safety, and environmental issues - understand the concept of sustainability - understand basic concepts of chemical product engineering - have knowledge of some practical applications of process and product engineering
Applying knowledge and understanding	- understand the basic principles underlying chemical engineering subject and is able to use them to set up and to solve (analytically, numerically, graphically) a variety of (bio)chemical engineering problems - be able to resolve (under supervision) a pre-defined research question - execute (under supervision) simple scientific experiments, test a hypothesis and analyse and interpret own experimental data in relation to data presented in scientific literature - be able to apply basic health, safety, and environmental issues - have an ability to analyse complex problems in the chosen orientation - have some experience in using appropriate software - be able to perform appropriate design in the chosen orientation - be able to calculate process and project costs - skills in planning and time management

Making judgements	- Ability to analyse material and synthesise concepts; - Ability to include aspects of safety and environment, technological, ethical, societal and economic consequences of (bio)chemical, and technological changes in the design products or processes. - The capacity to adapt to new situations and to make decisions
Communication	- be able to present and discuss effectively results of learning and collected data, in Dutch and in English, using modern presentation tools as appropriate - Interpersonal skills, relating to the ability to interact with other people and to engage in team-working. - be able to work in multidisciplinary teams - Communication competences, covering both written and oral communication, in English as well as in the language of the home country.
Lifelong learning skills	- Reflect upon personal knowledge, skills, attitudes and functioning, both individually and in discussions with others; - be able to learn on his/her own, and have a recognition of the need for life-long learning - design and plan their own learning path including making a well-founded choice for a follow-up master programme

MOLECULAR LIFE SCIENCES (BSc)

While institutions should be encouraged to break down the traditional barriers between the chemical sub-disciplines, it is realised that this process will not always be rapid. Thus the traditional classification is retained in what follows.

Compulsory modules (“the core”) will deal with the main sub-disciplines:

- Analytical chemistry
- Inorganic chemistry
- Organic chemistry
- Physical chemistry
- Biochemistry
- Cellular biology
- Molecular genetics
- Microbiology

Depending on the strategic policy of the department, semi-optional modules will deal with sub-disciplines such as:

- Biophysics
- Biochemical Engineering
- Bio-nanotechnology
- Bio-information technology
- Biotechnology
- Immunology
- Plant Physiology
- Virology

Bachelor	Molecular Life Sciences
Knowledge and understanding	- the major types of organic chemical reactions/mechanisms and the main characteristics associated with them; - the principles of quantum mechanics and their application to the description of the structure and properties of atoms and molecules; - the nature and behaviour of functional groups in organic molecules; - the principles of thermodynamics and their applications to molecular life science; - the structure and reactivity of important classes of biomolecules and the chemistry of important biological processes; - the building of living cells, the biological function of cellular structures, components and biomolecules and the interactions between biomolecules; - the properties and physiology of micro-organisms; - the principle techniques of biochemical and molecular genetic investigations;
Applying knowledge and understanding	- the capacity to apply concepts from chemistry and physics, handle and derive formulas, do calculations, analyse and solve theoretical problems in the fields of organic and chemical biology, physical chemistry, thermodynamics, biophysics and spectroscopy;

	- the capacity to apply mathematical knowledge, methods and techniques from linear algebra and calculus and use relevant software to solve mathematical problems, in the domain of the molecular life sciences; - explain the relationships between structure and reactivity of molecules and apply concepts and theories in synthesis, catalysis, biochemistry and molecular biology; - information-management competences, in relation to primary and secondary information sources, including information retrieval through on-line internet searches; - execute (under supervision) simple scientific experiments in the various fields of molecular life sciences including analytical, physical and organic chemistry, biochemistry, molecular biology, biophysics and spectroscopy, test a hypothesis and analyse and interpret own experimental data in relation to data presented in literature and on internet; - resolve (under supervision) a pre-defined research question in the field of molecular life sciences into verifiable research; - develop and execute (under supervision) a research plan in at least one of the domains of the molecular life sciences in which research question, hypothesis, experimental set-up and data analysis are described in relation to relevant literature; - skills in planning and time management;
Making judgements	- demonstrate academic conduct by generating and recognizing creative ideas and recognizing limits of scientific knowledge; - ability to include safety, environmental, ethical, societal considerations that are intrinsically related to being active in the molecular-sciences domain in his decisions;
Communication	- process, present and discuss results of learning and collected data, both orally and in writing in Dutch and in English; - participate in multi-disciplinary teamwork and discussions with other people;
Lifelong learning skills	- reflect upon personal knowledge, skills, attitudes and functioning, both individually and in discussions with others; - design and plan their own learning path including making a well-founded choice for a follow-up master programme or a position in the labour market.

BIOPHARMACEUTICAL SCIENCES (BSC)

While institutions should be encouraged to break down the traditional barriers between the chemical sub-disciplines, it is realised that this process will not always be rapid. Thus the traditional classification is retained in what follows.

Next to the fundamentals of Science&Natural Sciences, compulsory modules (“the core”) will deal with the main sub-disciplines:

(Pharmaco)Chemistry

- Organic chemistry
- (Bio)Analytical chemistry
- Computational (Pharmaco)chemistry
- Medicinal chemistry
- Biology of the cell and human body
- Biochemistry and Molecular Biology
- Cell Biology
- (Patho)physiology
-

Drug action

- Applied pharmacokinetics and dynamics
- (Molecular) Pharmacology
- Pharmaceutical toxicology

Depending on the policy strategy of the department, semi-optional modules will deal with sub-disciplines such as:

Biopharmaceuticals

- Radiopharmacochemistry
- Pharmacy
- Bio-informatics

Bachelor	Biopharmaceutical Sciences
Knowledge and understanding	- the major types of organic chemical reactions/mechanisms and the main characteristics associated with them; - the principles of the structure and properties of atoms and molecules; - the nature and behaviour of functional groups in organic molecules; - the principles of thermodynamics and their applications to pharmaceutical sciences; - the structure and reactivity of important classes of biomolecules and the chemistry of important biological processes; - the building of living cells, the biological function of cellular structures, components and biomolecules and the interactions between biomolecules; - the relation between physiology of the (human) body, pathology and interaction with drugs ; - the principle techniques of cell biological, biochemical, molecular genetic investigations; - the principles and applications of computational methods in pharmaceutical sciences - the principles of the drug discovery and development process
Applying knowledge and understanding	- the capacity to apply theoretical concepts and analyse and solve research problems in the core domain of (bio)pharmaceutical sciences

	- explain the relationships between structure and (re)activity of molecules and apply concepts and theories in synthesis, pharmacology, pharmacokinetics, toxicology, analytical chemistry, biochemistry, molecular biology, and (patho)physiology - the capacity to apply mathematical and statistical knowledge, methods and use relevant software to solve theoretical problems in the domain of the (bio)pharmaceutical sciences; - information-management competences, in relation to primary and secondary information sources, including information retrieval through on-line internet searches and, critical assessment of the obtained information - execute (under supervision) simple scientific experiments in the various fields of pharmaceutical sciences including analytical sciences, organic chemistry, biochemistry, molecular biology, (patho)physiology, computational chemistry, (molecular) pharmacology, applied pharmacokinetics and dynamics, and pharmaceutical toxicology, test a hypothesis and analyse and interpret own experimental data in relation to data presented in literature and databases; - resolve (under supervision) a pre-defined research question in the field of (bio)pharmaceutical sciences by verifiable research; - design (under supervision) a research plan in at least one of the domains of the (bio)pharmaceutical sciences in which research question, hypothesis, and experimental set-up are described in relation to relevant literature, evaluate the plan against the opinion of fellow researchers, and execute experiments, data-analysis and interpretation of results in relation to relevant literature; skills in planning and time management
Making judgements	- demonstrate an academic attitude by generating and recognizing creative ideas and recognizing limits of scientific knowledge; - ability to select appropriate (bio)pharmaceutical laboratory and/or computational techniques and research models for testing a research hypothesis. - ability to include safety, ethical, societal and economic consequences of biological, chemical and technological changes in research into the design and development of drugs;
Communication	- process, present and discuss verbally and in writing about results of learning and collected experimental results in Dutch and English; - co- operate in a multi-disciplinary team on a pre-defined pharmaceutical-oriented research question, design or development problem
Lifelong learning skills	- reflect (under supervision) upon personal knowledge, skills, attitudes and functioning, both individually and in discussions with others; - design and plan their own learning path; - make a well-founded choice for a follow-up master programme.

Domain specific learning outcomes of master programmes

Content

In this section the Dublin Descriptors are “translated” into more domain specific learning outcomes of the different fields of the domain of chemical sciences. Each master programme contains a core programme, optional courses, and individual work in the form of thesis research and/or (industrial) internship.

Individual Work or Master Thesis Work

The academic goal of *Individual Work* in chemical sciences is to give graduates a research experience much broader and deeper than that involved in the limited Bachelor Thesis. The intention is the graduate will successfully complete a research project, the outcome of which is of a quality that is potentially publishable. Thus *Individual Work* normally carries at least 30 credits. The report on the *Individual Work* is often called the MSc Thesis work and will be written in the language prescribed by the institution and defended according to the rules of the institution. Its supervision and assessment must be transparent.

Distribution of credits

Each individual institution will of course make its own decision as to the distribution of credits between compulsory, semi-optional and elective modules. It will however be necessary to define a "core" in the form of a recommended minimum number of credits for the main sub-disciplines, mathematics and physics. This "core" should neither be too large nor too small, and a volume of 50% of the total number of credits, i.e. 60 out of 120, seems a good compromise in view of the different philosophies present in Europe. In general the MSc programme consists of at least 30 credits of the deepening or specialising courses; together with at least 30 credits of a master thesis or other individual work.

In summary most master programmes have the following global distribution of credits:

- ≥ 25 -60 credits are allocated to the core in the form of deepening or specialising courses,
- ≥ 30 -65 credits to the master thesis or academic internship
- The remaining credits (30 of which may come from modules not dealing with chemical sciences,) are freely allocable.

CHEMISTRY (MSc)

Master	Chemistry
Knowledge and understanding	- have knowledge and understanding that is founded upon and extends that of the Bachelor's level in chemistry, and that provides a basis for originality in developing and applying ideas within a research context
Applying knowledge and understanding	- have the ability to apply their knowledge and understanding, and problem solving abilities, in new or unfamiliar environments within broader (or multidisciplinary) contexts related to chemical sciences
Making judgements	- have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on ethical responsibilities linked to the application of their knowledge and judgements
Communication	- have the ability to communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously
Lifelong learning skills	- have developed those learning skills that will allow them to continue to study in a manner that may be largely self-directed or autonomous, and to take responsibility for their own professional development. - have competences which fit them for employment as professional chemists in chemical and related industries or in public service

CHEMICAL ENGINEERING (MSc)

Master	Chemical Engineering
Knowledge and understanding	- The graduates have acquired extensive and profound knowledge of mathematics, chemical engineering and other sciences which enable them to carry out scientific work and to act responsibly in their professions and in society. They have followed a number of advanced courses in for example multiphase reactor engineering, catalysis and/or transport phenomena. They are aware of new developments in their field.
Applying knowledge and understanding	The graduate is able to: - analyse and solve problems scientifically, even if the definitions are incomplete or are formulated in an unusual way and show competing specifications; - abstract and formulate complex problems from a new or a developing field; - apply innovative methods in solving problems based on fundamental principles - develop concepts and solutions to design problems based on fundamental principles but also to design problems which are posed in an unusual way – if necessary involving other fields; - develop /design new products, equipment, processes or methods; - tackle a real chemical engineering problem by a scientific approach: - recognise the need for information, to find and provide information: - plan and carry out theoretical and experimental research independently: - evaluate data critically and to draw conclusions from it: - examine and evaluate the application of new and emerging technologies. - familiarise themselves with new tasks systematically and without taking too long; - think systematically about the non-technical effects of an engineer's job and to include these aspects responsibly in what they do; - find solutions which require very considerable competence as far as methods are concerned.
Making judgements	- Ability to classify knowledge from various fields methodically and draw systematic conclusions from it and also to deal with complexity; - Ability to evaluate data and information critically and to draw conclusions from it: - To examine and evaluate the application of new and emerging technologies.
Communication	The graduate is able to: - communicate effectively, including in English, with specialists and non-specialists, using modern presentation tools as appropriate; - work individually and as team members in international and/or multidisciplinary teams; - understand the impact of engineering solutions in an environmental and societal context; - understand professional and ethical responsibility;
Lifelong learning skills	- have developed those learning skills that will allow them to continue to study in a manner that may be largely self-directed or autonomous, and to take responsibility for their own professional development. - have competences which fit them for employment as professional chemical engineers in chemical engineering and related industries or in public service.

(Molecular) Life Sciences (MSc)

Master	(Molecular) Life Sciences The graduate:
Knowledge and understanding	- has knowledge and understanding of current Molecular Life Sciences subjects and is built upon the Bachelor's level of various Life Sciences programmes. - is also familiar with the use of advanced experimental approaches, providing the basis for <u>originality in developing and applying ideas within a research context.</u>
Applying knowledge and understanding	- is able to apply advanced research methods in the field of (bio-)chemistry, biophysics, molecular biology, and/or bioinformatics in developing and executing a research project. - <u>can solve problems in a multidisciplinary manner</u>
Making judgements	- is able to critically evaluate research questions and results and defend points of view and conclusions - can give feedback in writing and orally. - has the skills to critically read and interpret the scientific literature and apply new developments and experimental approaches in his specialised domain. - <u>can evaluate ethical and societal issues associated with biomolecular research and its applications</u>
Communication	- can present and discuss research results in writing and speaking - can function in a research team and in a multidisciplinary academic research setting
Lifelong learning skills	- has strategic, critical thinking and problem solving abilities - can in the context of a research team, develop and execute research and communicate the results and implications with peers - can incorporate and interpret new knowledge and insights into existing scientific theories - is able to adjust and redefine hypotheses and models explaining biomolecular processes - can respond to ethical, societal and global considerations in practicing his profession

Biopharmaceutical Sciences technology (MSc)

Master	Pharmaceutical Sciences
Knowledge and understanding	- has a sound theoretical and practical understanding of modern pharmaceutical sciences - has a thorough knowledge of theoretical and experimental methods as well as research experience in at least one specialist area of pharmaceutical sciences
Applying knowledge and understanding	- the ability to make an independent analysis of scientific problems, analysis of relevant specialist literature, formulate verifiable hypotheses, and set up a research plan and carry out research and critical reflection on one's own research and that of others and in relation to relevant literature.
Making judgements	- demonstrate an academic attitude by: - think critically - reason logically - generate creative ideas

	- recognise the limits of scientific knowledge; - judge and reflect on the technological, ethical, societal and economic consequences of drug research to come to an ethically sound attitude and corresponding execution of one's professional duties
Communication	- communicate verbally and in writing about the results of learning, experiments and project work with specialists and wider audience; - co-operate in a multi-disciplinary team (including planning activities, taking responsibilities and motivating co-workers) on a pharmaceutical-oriented research question, design or development problem; -
Lifelong learning skills	- has strategic, critical thinking, and problem solving abilities - can in the context of a research team, develop and execute research and communicate the results and implications with peers - can incorporate and interpret new knowledge and insights into existing scientific theories - is able to adjust and redefine hypotheses and models explaining pharmaceutical research processes - can respond to ethical, societal and global considerations in practicing his/her profession

APPENDIX 2: Betrokkenen universiteiten 2024-2025

LEI

Lies Bouwman

Sander Wezenberg

RU

Koen van Asseldonk

Wilhelm Huck (Raad van de Scheikunde)

Paul Kouwer

Floris Rutjes

RUG

Michael Lerch (HCA werkgroep)

TUD

Hanno Van Keulen

Monique van der Veen

TUE

John Van der Schaaf

UM

Hanne Diliën

Romano Orru (HCA werkgroep)

UT

Leonie Krab-Hüsken

UU

Pieter Bruijninx (HCA werkgroep)

Bert Klein Gebbink

Eelco Vogt

UvA

Gert-Jan Gruter (Avantium),

Jocelyne Vreede

VU

Celia Fonseca Guerra

Aletta Kraneveld

Eelco Ruijter

WUR

Harry Bitter (HCA werkgroep)

Sonja Isken

OVERIG

Remko Achten (NWO, HCA werkgroep)

Onno De Vreede (CHEMISTRYNL, HCA werkgroep)

APPENDIX 3: (ChatGPT, 2-dec-2024)

Vraag aan ChatGPT: Wat houdt de Chemicus van de Toekomst in? Hoe kan deze het beste worden opgeleid?

De chemicus van de toekomst zal niet langer een eenduidig profiel volgen. De complexiteit en de veelzijdigheid van maatschappelijke uitdagingen vereisen een breed scala aan chemische specialismen en vaardigheden. Hierdoor ontstaan verschillende typen chemici, elk afgestemd op specifieke behoeften van de samenleving, industrie en wetenschap. Dit vereist een flexibele en multidisciplinaire benadering van chemieonderwijs en professionalisering.

Soorten Chemici van de Toekomst

1. De Fundamentele Chemicus

- **Rol:** Richt zich op het begrijpen van de kernprincipes van chemie, zoals moleculaire structuren, reacties en thermodynamica.
- **Toepassing:** Ondersteunt interdisciplinair onderzoek en innovatie door robuuste kennis van fundamentele chemische concepten.
- **Vaardigheden:** Diepgaande kennis van chemische kernvakken, gecombineerd met basiskennis van aanpalende wetenschappen zoals fysica en biologie.

2. De Probleemgestuurde Chemicus

- **Rol:** Werkt aan maatschappelijke uitdagingen, zoals klimaatverandering, watermanagement, en circulaire economie.
- **Toepassing:** Ontwikkelt duurzame materialen, processen en technologieën.
- **Vaardigheden:** Interdisciplinariteit, systeemdenken en sterke samenwerking met andere disciplines zoals engineering en milieuwetenschappen.

3. De Data- en Technologiegerichte Chemicus

- **Rol:** Integreert digitale technologieën zoals kunstmatige intelligentie, data science en programmeervaardigheden in chemisch onderzoek.
- **Toepassing:** Analyseert complexe datasets en automatiseert processen, zoals moleculaire modellering en high-throughput screening.
- **Vaardigheden:** Kennis van datawetenschap, basis programmeren en begrip van digitale tools in chemische toepassingen.

4. De Toegepaste Chemicus

- **Rol:** Richt zich op praktische toepassingen in de industrie, zoals proceschemie, farmaceutische ontwikkeling en chemische technologie.
- **Toepassing:** Verbindt fundamentele wetenschap met industriële innovatie en productie.
- **Vaardigheden:** Praktisch inzicht in schaalvergroting, regelgeving en commerciële haalbaarheid.

5. De Educatieve en Outreach-Chemicus

- **Rol:** Bevordert chemische kennis en bewustzijn in de samenleving, met speciale aandacht voor jonge generaties.
- **Toepassing:** Werkt als docent, communicatiespecialist of projectmanager bij outreach-initiatieven.

- **Vaardigheden:** Sterke didactische en communicatieve vaardigheden, gecombineerd met chemische basiskennis.
 - 6. **De Interdisciplinaire Chemicus**
 - **Rol:** Werkt op het grensvlak van chemie en andere disciplines zoals biologie, geneeskunde of milieuwetenschappen.
 - **Toepassing:** Ontwikkelt innovatieve oplossingen die meerdere vakgebieden verbinden.
 - **Vaardigheden:** Kennis van chemische kernvakken én expertise in andere wetenschappen, zoals biotechnologie of nanotechnologie.
-

Aanbevelingen voor Onderwijs en Onderzoek

Om deze diverse typen chemici op te leiden, moeten universiteiten flexibele en modulaire curricula ontwikkelen die rekening houden met de verscheidenheid aan loopbaanpaden. Dit kan worden gerealiseerd door:

- **Flexibele programma's:** Studenten keuzes bieden tussen specialisaties zoals data science, duurzaamheid of fundamentele chemie.
- **Interdisciplinair onderwijs:** Modules integreren die samenwerking met andere disciplines aanmoedigen.
- **Praktijkgericht leren:** Stages, projectmatig werken en samenwerking met de industrie inbedden in programma's.
- **Life-long learning:** Programma's ontwikkelen voor permanente educatie, zodat chemici zich kunnen blijven aanpassen aan veranderende eisen van het werkveld.

De toekomst van chemieonderwijs moet dus niet alleen aansluiten bij de wetenschappelijke en technologische vooruitgang, maar ook bij de verscheidenheid aan rollen die chemici in de maatschappij zullen spelen.