هيئة تقويم التعليم والتدريب
Education & Training Evaluation Commission

اعتماد
NCAAA

Key Learning Outcomes for Chemistry Programs

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هيئة تقويم التعليم والتدريب
Education & Training Evaluation Commission

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Introduction

Based on the mandate of the Education and Training Evaluation Commission (ETEC), issued by Royal Decree No. 108, dated 14/2/1440 H, ETEC is mandated to "building systems for evaluation and accreditation - including institutional and programmatic - in education and training, including rules, standards, frameworks and indicators and its terms, procedures, approval, and application." And based on the authority's keenness to build and develop high-quality national academic programs, the authority has worked on preparing specialized academic standards for BSc Chemistry programs.

The standards contribute to setting the minimum curriculum requirements of Chemistry undergraduate programs to ensure their academic quality, and to assure their ability to produce highly qualified professionals in the field of Chemistry with the knowledge and skills required by the market and the national needs, in line with best practices and academic requirements for this field.

Goals

The main goal of this work is to develop specialized Learning Outcomes (SLOs) that should represent the minimal achieved by Chemistry students at graduation. It will direct programs, course design and organization, building the curriculum map including the appropriate teaching and learning strategies, assessment tools, evaluation strategy, and link academic and professional aspects.

Methodology

This document describes the minimum knowledge units (KUs) and learning outcomes (LOs) in the field of Chemistry, which graduates are expected to obtain upon completion of the program. The KU-specific learning outcomes specify the minimum of what students should know or be able to do after successfully completing the KU.

The methodology follows the following phases:

1. Identifying International Benchmarks.
2. Identifying Program Key Learning Outcomes.
3. Identifying Curriculum General Criteria
4. Identifying the General Knowledge Units.
5. Identifying the Specialized Knowledge Units for each General Knowledge Unit.
6. Identifying the Specialized Learning Outcomes for each Specialized Knowledge Unit.

It is important for educational institutions to take into account the depth and expansion; and to include LOs related to communication skills and values in the curricula. Educational institutions can offer the desired elective KUs that are relevant to their programs and students can choose from them to complete their graduation requirements. It is important to note that a KU is not necessarily a credit course. A KU may be covered by one or more credit courses and a credit course may cover one or more KUs partially or completely. The KUs are derived from analyzing of nine QS high ranked and two local University international and local programs (see Appendix A).

This document was developed by the ETEC in cooperation and coordination with different entities in the field of Chemistry, such as three local chemistry departments representing three local universities, Ministry of Energy, Saudi Space Agency, Ministry of Industry and Mineral Resources, National Industrial Development and Logistics Program, Saudi Geological Survey and Saudi Standards, Metrology, and Quality Organization.

Scope and Uses

This document covers the bachelor's degree programs in the field of Chemistry. The document can be used and applied to Chemistry programs offered by higher educational public and private institutions in Saudi Arabia.

Terms

ETEC: Education and Training Evaluation Commission – Saudi Arabia.

Knowledge Units: Thematic groupings that encompass multiple related topics, where the topics cover the required curricular content for each KU. Each KU contains a set of learning outcomes.

Essential Knowledge Units (EKUs): The required topics in Math, Physics and Computer Programming.

General Knowledge Units (GKUs): Knowledge Units that introduce students to the main topics in Chemistry. All students majoring in any field of Chemistry should complete these GKU's.

Key Learning Outcomes (KLOs): It describes what students are expected to know and will be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program.

Learning Outcomes (LOs): Phrases describing what a learner should know, understand, and be able to do at the end of the program. They represent the bottom line of the learning process.

NQF: National Qualifications Framework.

Specialized Key Learning Outcomes (SLOs): The specificity needed for interpretation of the general criteria as applicable to a given discipline.

Specialized Knowledge Units (SKUs): Knowledge Units that introduce students to intermediate and advanced topics in a major.

Students Professional Development Domain (SPDD): Knowledge and skills domain at the advanced level of chemistry curriculum that incorporate applied chemistry courses with students' projects to develop students' work-oriented and professional skills.

Chemistry Experience Units (CEUs): It is learner-centered experience Units under SPDD where students should demonstrate and practice values, develop responsibility, ethical and scientific conduct, employment skills such as in leadership, management and organizational skills, networking, engagement with literature, oral and written communication. All activities involved under chemistry experience units are regarded as students work projects.

Applied Chemistry Units (ACUs): It is Applied Knowledge and Skills Units under SPDD that introduce students to chemical industries, and a broad variety of alternative scientific, business, and technical sectors associated with it. ACUs provide a range of required elective chemistry and non-chemistry courses to develop students' knowledge and skills in certain areas of chemistry-related labor market.

Key Learning Outcomes

As discussed in Appendix B, the alignment of NQF domains with standardized chemistry curriculum domains obtained from international benchmarking proposed three learning domains applicable to chemical sciences and their employment market in the Kingdom. These three domains are (i)

Knowledge, (ii) Practical Skills, (iii) Students Professional Development. The Practical Skills domain is composed of two subdomains (i) Laboratory Skills, (ii) Classroom Skills. Students Professional Development domain is achieved through two major curriculum units (i) Chemistry Experience Units, (ii) Applied Chemistry Units. The chemistry program curriculum should be structured across the abovementioned domains, knowledge, and skills units. Chemistry program learning outcomes should also be developed to strictly cover those domains. Therefore, on successful completion of a bachelor's degree in chemistry, graduates should be able to:

KLO1 Demonstrate a critical understanding of the key and core knowledge of the main branches of chemistry and related fields, as outlined GKUs and SKUs.

KLO2 Identify the interdisciplinary nature between chemistry branches to interpret and evaluate the practical applications of the essential facts, concepts, principles, and theories of chemistry.

KLO3 Predict and interpret chemical and physical changes that organic and inorganic materials undergo using appropriate chemical information, data, and rules.

KLO4 Practice health and safety regulations while handling chemicals and performing laboratory activities with the capability to conduct a sufficient risk assessment.

KLO5 Conduct accurate quantitative and qualitative measurements using standard chemical instrumentation and software and report experimental results with appropriate interpretation, calculations, and reasonable conclusions.

KLO6 Synthesize and characterize organic and inorganic materials using appropriate procedures, instrumentations, and chemical apparatus.

KLO7 Develop a systematic and reliable experimental record via precise observations of measurements and changes and assessment of the limit of accuracy of experimental data.

KLO8 Apply principles, laws and theories of chemistry and related physical and mathematical equations to solve complex chemical problems with appropriate approximation, precision, accuracy, and statistical validity.

KLO9 Solve chemical problems related to different applications of chemistry through critical thinking to develop appropriate rational, explanations and answers.

KLO10 Plan, execute and report project work by employing knowledge learned, practical skills developed previously in the program with effective use of chemical literature and retrieval of chemical methods.

KLO11 Present chemical data and reports scientifically in written and oral communication with proper scientific conduct and ethical responsibility.

KLO12 Lead and manage chemistry project work effectively, and demonstrate self-discipline, decision-making capabilities and engagement in team working to build a working network in chemistry related fields.

KLO13 Relate the learned chemistry knowledge and skills to future career and Plan for further professional training as a chemist.

Curriculum General Criteria

Based on benchmarking study of leading universities (Appendix A), and analyzing all knowledge units (KUs) and skills using Chemistry programs, it is found that these KUs are grouped in the following categories:

1. Essential knowledge units: [22 Credit hours]
2. General knowledge and skills units: [57 Credit hours]

3. Specialized knowledge units
4. Chemistry Experience Units [8 Credit hours]
5. Applied Chemistry Units [18 Credit hours]
6. University requirements, any other non-chemistry electives [15 credit hours]

Each group consists of different subgroups that is essential in any typical Chemistry curriculum. To show the importance of each of the subgroups, a range of allocated credit hours in a typical Chemistry curriculum is shown in the next section.

knowledge Units

The following table provides an overall view of the curriculum distribution of Knowledge Units: essential, general, specialized and others. The tables also provide general recommendation on the acceptable range of credit hours for each knowledge unit.

Essential Knowledge Units (EKU)

Calculated based on a minimum of [22] credits for Math, Physics and Computer Programming. This part of the knowledge units should not be used in standardized tests.

Table 1: Essential Knowledge Unit of [Chemistry]

#	EKU	Description	Minimum Requirements
1	Mathematics	• **Calculus 1** Limits and continuity of functions of a single variable. Differentiability, Techniques of differentiation. Implicit differentiation. Local extrema, first and second derivative tests for local extrema. Concavity and inflection points. Curve sketching. Applied extrema problems. The Mean Value Theorem and applications. • **Calculus 2** Definite and indefinite integrals of functions of a single variable. Fundamental Theorem of Calculus. Techniques of integration. Hyperbolic functions. Applications of the definite integral to area, volume, arc length and surface area. Improper integrals. Sequences and series: convergence tests, integral, comparison, ratio and root tests. Alternating series. Absolute and conditional convergence. Power series. Taylor and Maclaurin series. • **Calculus 3** Polar coordinates, polar curves, area in polar coordinates. Vectors, lines, planes, and surfaces. Cylindrical and spherical coordinates. Functions of two and three variables, limits, and continuity. Partial derivatives, directional derivatives. Extrema of functions of two variables. Double integrals, double integrals in polar coordinates. Triple integrals, triple integrals in cylindrical and spherical coordinates. • **Introduction to Differential Equation:** Techniques and applications of ordinary differential equations, including Fourier series and boundary value problems, and an introduction to partial differential equations.	11
2	Physics	• The basic laws and principles of Newtonian mechanics; oscillations, waves, and wave optics • The basic laws of electricity and magnetism; geometrical optics • Properties of electromagnetic fields, dipole and quadrupole fields and their interactions, chemical binding of molecules, electromagnetic properties of materials, Maxwell's equations, and properties of electromagnetic waves.	8
3	Computer Programing	**Introduction to computer programming for physical sciences**: Overview of computer hardware and software. Programming in Python with emphasis on	3

		basic program constructs: variables, assignments, expressions, decision structures, looping, functions, lists, files, and exceptions; Introduction to objects and classes. Programming in C with emphasis on pointers and functions with output parameters. Simple multidisciplinary problem solving in science, engineering, and business.	

- The above EKUs (22 Credit hours) are the minimum credit hours of essential knowledge units for standard chemistry programs.
- the minimum credit hours of essential knowledge should include tutorials and laboratories according to the nature of the knowledge unit, for example, Math requires tutorials, Physics and Programming requires laboratory credit hours. Therefore, the total contact hours that are allocated to laboratory and tutorials should not be less than he minimum credit hours of essential knowledge should include tutorials and laboratories according to the nature of the knowledge unit, for example, Math requires tutorials, Physics and Programming requires laboratory credit hours. Therefore, the total contact hours that should be allocated to laboratory and tutorials should not be less than 40% of the total contact hours of EKUs.
- Based on international best practices, the essential knowledge units may include biology and some other courses based on the tracks of the program as well as the mission of the institution and its programs.
- Chemistry programs may also include more Math & Computer Programming credit hours as essential knowledge units depending on the tracks of the program as well as the mission of the institution and its programs.

Program core Knowledge Units

Percentages are calculated based on a minimum of credits for the Chemistry program.

Table 2: Generalized and Specialized Knowledge Units of Chemistry

#	GKU	Weight%	SKU	Weight%
1	General Chemistry	14.0	1.1. Principle of Inorganic Chemistry	5.0
			1.2. Principle of Physical Chemistry	5.0
			1.3. General Chemistry Laboratory	4.0
2	Organic Chemistry	24.5	2.1. Principles of organic chemistry	7.0
			2.2. Organo-physical chemistry	7.0
			2.3. Bioorganic chemistry	3.5
			2.4. Organic Chemistry Laboratory	7.0
3	Physical Chemistry	24.5	3.1. Physical Chemistry of Bulk Matter	12.0
			3.2. Physical Chemistry of Microscopic Matter	5.5
			3.3. Physical Chemistry Laboratory	7.0
4	Inorganic chemistry	19.0	4.1. Bonding theories and structure	5.0
			4.2. Chemistry of elements	3.0
			4.3. Chemistry of inorganic materials	5.0
			4.4. Inorganic Chemistry Laboratory	6.0
5	Analytical Chemistry	18.0	5.1 General concepts in analytical chemistry	2.0
			5.2 Classical analytical chemistry	3.0
			5.3 Instrumental analytical chemistry	7.0
			5.4 Analytical Chemistry Laboratory	6.0

- The weight% of GKUs are calculated based on the total credit hours of GKUs, which is 57 credit hours.
- Credit hour calculations are based on a formula in which one 50-minute lecture, or two or three 50-minute laboratory or tutorial sessions over a 15-week teaching semester are regarded as one credit hour.

- The total contact hours of laboratory and tutorial sessions should be between 50-40% of the total contact hours of GKUs.
- Tutorial sessions should not be less than 10 % of the total contact hours of the total contact hours of laboratory and tutorial sessions.

Chemistry Experience Units (CEUs)

The aim of introducing Chemistry experience units as a chemistry curriculum criterion is to promote chemistry programs involvement with labor market in order to develop and enhance professional skills for chemistry graduates and foster students' career development in chemistry-related labor market. CEUs are calculated based on a minimum of [8] credits for required and elective experience. Chemistry Experience activities should account for a minimum of 180 contact hours of student contact hours in the final year of the program. CEUs are learner-centered experience Units within the advanced level of the program that:

- allows students to independently apply their knowledge and practical skills in various areas of learning and real-life situations.
- enables students to incorporate professional skills with chemistry knowledge and skills in order to acquire professional and career-related skills and establish a working network.
- prepares students for their career and identifies the appropriate future professional training.

CEUs include all activities that meet the above-mentioned requirements, examples, but not limited to the following:

1. Research Project,
2. Field Experience,
3. Literature Investigation,
4. Extended Case Study,
5. Collaborative Project,
6. Voluntary Project,
7. A year in Industry

Students in such activities should demonstrate and practice values, develop responsibility, ethical and scientific conduct, high skills in leadership, project management, organizational skills, engagement with literature, oral and written communication.

Applied Chemistry Units (ACUs)

Calculated based on a minimum of [18] credits for required and elective courses. ACUs provide a wide range of applied chemical courses in certain areas of chemical industries, in addition to some technical and non-technical courses that broaden students’ practical knowledge and skills. These courses are used as basis for applied tracks, and they should enable graduates to work in a wide variety of local and national industrial sectors. Examples of such industries can be seen appendix D. To emphasize the applied nature of the courses under Applied Chemistry Units, the applied courses should carry balanced theoretical and laboratory credit hours. Therefore, the laboratory contact hours of the applied courses should be not less than 50% of the total contact hours of all applied chemistry courses.

Appendix (A): International Practices analysis

The GKUs are derived from the following sources:

1. [American Chemical Society]
2. [Royal Society of Chemistry]
3. [9 Selected national and international Universities]

Table A1: International and local universities considered in the analysis of Chemistry program requirements.

#	University	Department name	US News Ranking 2023	QS University Ranking 2023
1	McGill - Canada	Chemistry	126	51
2	Texas A&M - USA	Chemistry	27	72
3	Illinois Urbana Champaign - USA	Chemistry	9	26
4	Wisconsin-Madison - USA	Chemistry	47	44
5	Minnesota Minneapolis -USA	Chemistry	60	59
6	National University of Singapore – Singapore	Chemistry	8	8
7	Nanyang Technological - Singapore	Chemistry	3	11
8	North Carolina at Chapel Hill	Chemistry	16	68
9	King Fahd University for Petroleum and Minerals - KSA	Chemistry	92	114

Required Subjects/Topics in Top International and Local Universities

An in-depth analysis of chemistry curriculum in the selected national and international chemistry programs was carried out to identify the major trends and best practices in chemistry curriculum, as can be seen in Table A2. It was apparent that all the examined chemistry programs showed significant similarities in terms of non-chemistry subject requirements such as math, physics, computer programming, biology, however, they differ slightly in the total number of credit hours and in biology whether I it's a requirement or elective requirement. It was also clear that all analyzed chemistry curriculum showed agreement in the inclusion of traditional chemistry branches in the curriculum, these include, general chemistry, organic, inorganic, physical and analytical chemistry. These branches are given the name General Knowledge Units in the current chemistry curriculum criteria. It was seen that these branches have list of major topics which all present in chemistry curricula that have been analyzed. These list of topics for each chemistry branch are named Specialized Knowledge Units in this document. All analyzed chemistry programs provide elective chemistry and non-chemistry courses, these electives, in some programs, present chemistry tracks that serve local industry. Therefore, it is strongly recommended that chemistry programs in the Kingdom should provide elective chemistry and non-chemistry courses to prepare students to work in the local chemistry-related industries. According to the surveyed chemistry programs and ACS and RSC requirements, it is a significant trend in modern chemistry curriculum that it provides students with chemistry experience credits. This can include research project, field training, case study, a year in industry, based on the program mission. Therefore, it is important for chemistry curriculum in the Kingdom to also adopt this trend but with flexibility in terms of what is required and what is elective.

Table A2: Chemistry program required Subjects/Topics in elite International and local Universities.

GKUs	SKUs	1	2	3	4	5	6	7	8	9	Count	
											Total	Note
General Chemistry	Principle of Inorganic Chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Principle of Physical Chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	General Chemistry Laboratory	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
Organic Chemistry	Principles of organic chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Organo-physical chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Organic preparations	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Polymer Chemistry	Y	Y				Y	Y	Y		5	C
	Bioorganic chemistry	Y	Y				Y	Y	Y	Y	5	B
	Organic Chemistry Laboratory	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
Inorganic Chemistry	Chemistry of element	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Material Chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Inorganic Chemistry Laboratory	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
Analytical Chemistry	Qualitative and quantitative analysis	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Instrumental analysis	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Analytical Chemistry Laboratory	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
Physical Chemistry	Chemical thermodynamics	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Kinetic and catalysis	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Surface chemistry (Elective)				Y		Y	Y	Y		4	C
	Theoretical chemistry	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Physical Chemistry Laboratory	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
Chemistry Experience	Principle of Scientific research	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Research project	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Seminar		Y	Y			Y	Y	Y	Y	6	B
	Field experience										0	C
Applied Chemistry	Technical Electives	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A
	Non-Technical Electives	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	A

- Any specialized knowledge unit that was taught by 65 % or more of the universities were considered an important SKU and recommended and Labelled "A."

- If the comparison showed that a particular SKU scored below 65% and was believed to be important, they were further screened by applying another acceptance condition as defined in the FE exam by QIYAS and SCE. The SKUs that satisfy this condition are recommended and labelled by "B."
- SKUs not meeting the above conditions were be recommended, labeled by "C," and eliminated from Specialized Learning Outcomes.
- Comparisons were made based on the course descriptions. If no syllabus is available, consensus ware made.

Approach to setting the domains of chemistry programs.

Chemistry is an experimental science and chemistry program graduates are placed in Saudi Arabia over a wide range of sectors with different nature and applications of chemical sciences. Therefore, developing effective domains of unique nature for chemistry, and related to Saudi jobs market, for chemistry programs is vital. Diagram 1. describes the approach followed for setting the domain of chemistry programs. An overview analysis of where chemists work and what their primary duties should be available in order to identify main stakeholders and recognize the critical and professional skills of chemists. This is an important step to consider while developing learning outcomes and is described in section 2.1 and 2.2.

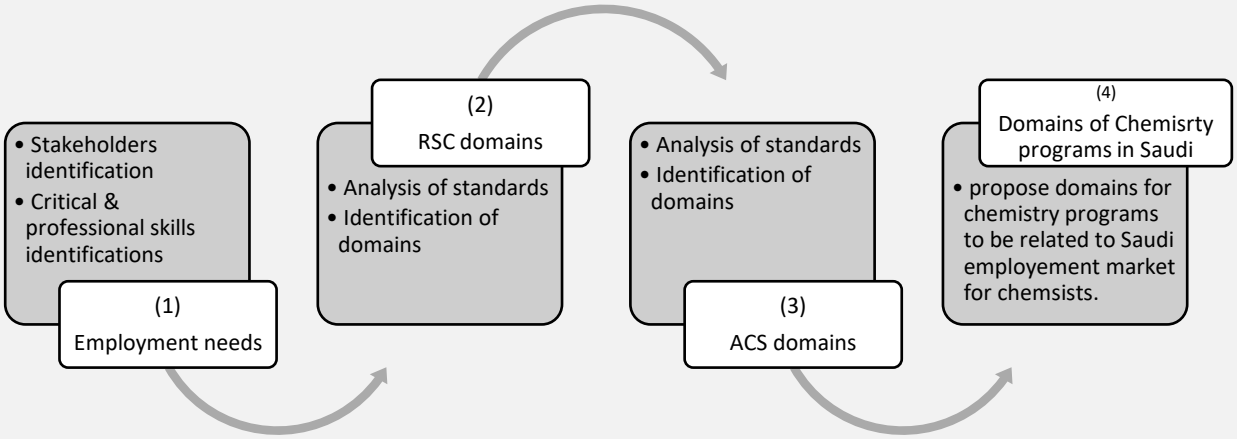

Diagram 1. Approach to setting the domain of chemistry programs in Saudi Arabia

In step 2 and 3, the accreditations standards and requirements for chemistry programs set by both RSC and ACS were critically analyzed, as can be seen Diagram 2. The results of these two steps clearly show that the domains of RSC and ACS are almost identical, particularly knowledge domain.

1. Alignment of knowledge and skills domains

An in-depth analysis of KSA-NQF domains was carried out along with comparison with RSC and ACS domains. The main components of each domain were identified. It was clearly found that Knowledge Domain is identical in KSA-NQF, ACS and RSC referring to a broad background in chemical principles and in-depth study of chemistry or chemistry-related areas. Skills domain is inherently present in KSA-NQF, ACS and RSC domains. Practical skills developed by laboratory experience are considered a primary domain in chemistry programs in both ACS and RSC. Laboratory experience provides practical

application of knowledge in chemical sciences. Therefore, the skills domain in chemistry programs should reflect the experimental nature chemistry and hence, called practical skills.

However, skills in KSA-NQF, there are still two main components which are: critical evaluation of approaches and methods in solving problems. For chemistry programs, these two skills are still necessary. They are also required by ACS and RSC standards and by chemistry career. They are presented in ACS and RSC standards as problem-solving, critical thinking and analytical reasoning. These skills are critical for professional chemists, and they can be neglected in chemistry programs because they are linked to the theoretical aspect of chemistry which are delivered in the classroom and the time of traditional lectures do not allow practicing these skills. To help overcome this challenge, we first classify problems in chemistry to be of theoretical and practical nature. Therefore, we propose to subdivide the practical skills domain into two sub-domains: laboratory-based practical and skills and classroom-based practical skills. An explanation of these sub-domains is as follows:

Practical Skills	
Laboratory-based: problems of practical nature	Classroom-based: problems of theoretical and numerical nature
• Hands-on experience in laboratory • Operation of modern instrumentation using standard operating procedures • Plan, observe, record, analyize, report a scientific experiment. • Practice with safety and good scientific conduct	• Developed via tutorials, in-class exercises, or homework exercises with oriented feedback. • Apply scientific laws and relations to solve complex problems. • Critically evaluate method of solutions to scientific problems related to a discipline, profession, or field of work;

2. Alignment of (Values, Autonomy & Responsibility: Competence) domain

Competence is the ability of a student to perform in real life, which implies interaction in various social situations, cultural settings, and working conditions. In other words, the competences only fully appear when students are put into a practical context related to their future work and life. It is, therefore, work-oriented more than curriculum-oriented. KSA-NQF describes competence in three sub-domains:

1. Autonomy and responsibility in the application of knowledge and skills.
2. Practice of knowledge and skills in real and work situations.
3. Attributes relating to the behavioural and social dimension of learning, work attitude, and ethical considerations.

The analysis and comparison of competence domain and sub-domain in KSA-NQF with RSC and ACS standards are presented in Table 2. From the comparison, we can realize that the description of competence sub-domain; autonomy, responsibility, and practice, contain some learning outcomes such as managing complex technical or professional activities, working in a peer relationship, decision making, analyzing, and interpreting complex information and more others. These learning outcomes match with great similarity the learning outcomes in project work, capstone experience in ACS and RSC standards. It implies that the two sub-domains of competence, autonomy, responsibility, and practice could be merged in one main domain called Chemistry Experience. This will simplify the domain and facilitate the implications within chemistry programs by adding a practical dimension of the domain.

The attributes sub-domain in KSA-NQF are concerned with building a professional relationship, displaying confidence, potential for leadership and entrepreneurialism, being a respectful, team-oriented, right personal attitude towards values and ethics. ACS and RSC, however, introduced professional skills and development domain. In this domain, a significant number of

personal and professional skills are required such as time management, communication skills, information management, information technology, ethics, and safety
skills. To make an alignment this domain with KSA-NQF, we can conclude that the domain professional development, as described in ACS and RSC, has a broader context than 'attributes,' it covers all learning outcomes described in attributes domain, with even more focus on chemistry careers related skills. Therefore, Students professional development appears to be more relevant to chemistry programs and it will ensure to cover those requirements which 'attributes' domain in KSA-NQF contains.

In conclusion, the alignment of KSA-NQF competence domain with ACS and RSC domains to produce domains of chemical nature for chemistry programs in Saudi Arabia has resulted in the following table 4. As can be seen from the table, competence domain in chemistry program learning outcomes will be developed in one major domain, Student Professional Development, which includes two different types of learning units, (i) Chemistry Experience Units, and (i) Applied Chemistry Units. These units represent the advanced level of the program, and they show programs administrations where to provide experiences and/or courses for students to enable them to develop autonomy, responsibility and other professional skills stated in KSA-NQF, ACS and RSC standards.

Table 2. Alignment of competence domain in KSA-NQF with RSC and ACS

KSA-NQF	Competence		
	Values, Autonomy & Responsibility	Practice	Attributes
RSC	Project work		Professional Skills
ACS	Research	Capstone experience	Students' development skills
Chem Prog.	Students Professional Development		
	Chemistry Experience Units		Applied Chemistry Units

Table 3. The proposed domains of chemistry programs in the Kingdom of Saudi Arabia

Program level	**Chemistry Domains**		
Foundation level	Knowledge		
	Practical Skills	Laboratory-based	
		Classroom-based	
Advance level	Values, Autonomy & Responsibility: Competence	Student Professional Development	Applied Chemistry Units
			Chemistry Experience Units

3. Defining Chemistry program domains

As discussed in section previously, we propose reasonable domains for chemistry programs in Saudi Arabia. The proposed domains show a great alignment with KSA-NQF and with evidence from benchmarking international chemical societies, namely RSC and ACS. The proposed domains are described in detail as follows:

1. Knowledge:

- A breadth study of fundamentals of the main chemistry branches, organic, inorganic, analytical, physical.
- It is also a demonstration of an in-depth understanding of fundamental chemical principles and their modern applications.
- It is recalling, critical interpretation and application of base knowledge in chemistry.

2. Practical skills:

Practical skills in chemistry programs are an essential component to support knowledge and theoretical aspects of chemistry curriculum. It is the application of chemistry curriculum knowledge through practical laboratory.

a. Laboratory-Based Skills

Chemistry students should be able to:

- synthesis, measure, manipulate chemical apparatus and operate modern instrumentation.
- plan experiments with objectives, monitor and measure properties changes, document observations and procedures.
- handle chemicals and hazardous materials and tools safely and conduct a risk assessment.
- interpret data and explain any limits of accuracy and precision of results, write and present scientific reports.
- evaluate and analyze methods of experiments according to the appropriate chemical references.

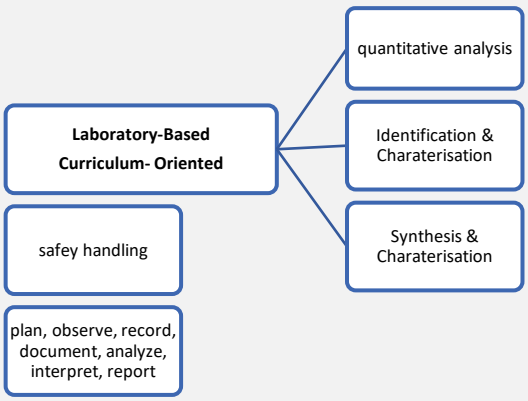

Diagram 3. Main activities of practical skills in chemistry laboratory

b. Classroom-based practical skills

A significant component of practical skills of chemical science is not of laboratory nature, it is the application of chemistry principles, rules, laws, and theories:

- to solve problems of mathematical or theoretical nature, or problems related to the application of science in real life.
- With critical thinking and analytical reasoning skills to solve theoretical aspects of chemical problems

These skills can be developed in the classroom, tutorials, or homework. Therefore, the program should devote certain number of credit and contact hours to allow student to Perform and develop these classroom-based skills.

3. Student Professional Development:

Student Professional Development domain, with Chemistry Experience Units and Applied Chemistry Units, aims to foster strong collaboration and partnership between chemistry programs and the employment sector, to provide work-based and work-place learning for chemistry students, thus addressing student's long-term employability. Values, Autonomy and Responsibility domain in the recent NQF replaces competence in the previous KSA-NQF, however, for the sake of simplicity, we define competence is the ability of a student to perform in real-life experience, which implies interaction in various working conditions. In other words, students can demonstrate their competence as chemists only and fully when they are put into practical experiences within the program related to future work and life. It is, therefore, work-oriented more than curriculum-oriented. In conjunction with knowledge and practical skills, competence is also about personal attributes, values, ethical aspects, responsibilities, level of autonomy in performing tasks and activities. Here, we describe the

practical domains of chemistry programs where competence can emerge, be developed, and be assessed.

a. Chemistry Experience Units:

It is a learner-centered course that provides experience and activity at the advanced level of the program in order to allows students to independently apply their knowledge and practical skills in various areas of learning and real-life situations. Students can choose from a list of courses or experiences what suits their future career. Any activities performed by students under this domain should be regarded as a student project work to lead, perform, and present. A student should satisfy one or some of the following courses, or any similar further activities that meet the requirements of this domain:

1- **Research Project:** It is an individual experimentation work conducted in the final year of chemistry program under supervision of a senior chemistry faculty. Students in research project may participate in an ongoing chemistry research projects in or outside the program. Students in Research Project may investigate topics in basic or applied chemistry or in an interdisciplinary area of science. Students are expected to produce a mini research thesis and may publish their work in peer-reviewed journal.
2- **Field Experience:** It is the placement of students in chemical industry for the purpose of training on instrumentations and performing chemical tasks in industry in order to experience chemistry in a real-world setting. Students are expected to perform toward achieving clear and planned tasks and produce, present, and discuss final achievement report. Supervision from the training site as well as from the program is required in Field Experience.
3- **Literature Investigation:** It is a practice of the theoretical aspect of scientific research by demonstration an in-depth understanding of fundamental chemistry required to analyze and critically evaluate certain research topics and questions in chemistry using chemistry literature. Students are expected to effectively communicate scientific information in writing literature investigation report which to be presented and discussed orally.
4- **Extended Case Study:** It is a theoretical research technique where students are required to propose solutions to real chemistry problems or answer real research questions using their knowledge and skills in chemistry incorporated with some real information, real data for real situations.
5- **Collaborative Project:** It is working with other individuals in a team, either a leader or a member of the team to achieve the goals of a chemistry service project which targets at engagement of students with internal or external stakeholders such as industries, research, or analytical labs, tc. Therefore, students will have multiple exposures to the real word using their knowledge and skills in chemistry. Students are expected to measure and report in written and oral forms the achievements of the project goals and KPIs.
6- **Voluntary Project**: It is a form of collaborative work where students are required to develop and implement voluntary projects in collaboration with individuals or organizations outside the program to achieve certain goals. Such projects target delivering chemistry knowledge and skills to the society in different forms and exposures. Examples of such projects include, but are not limited to, school teaching, science days, campaigns etc. students are expected to measure and report the achievement of project goals and KPIs.
7- **A year in Industry:** It represent the most advanced engagement of chemistry program with the chemical industry. It is a complete placement of chemistry student in chemical company as full-time paid employee before returning to the program to obtain his/her chemistry degree. The aim of this practice is enabling student to gain solid understanding of chemical industry and to establish strong professional career in chemistry. It can be

noted that this year in industry is a practice similar to the internship year for medical sciences. Therefore, benchmarking of the implementation of this practice in chemistry with medical programs can be conducted.

For successful implementation of CEUs in chemistry curriculum, programs are encouraged to carefully consider the following points:

- The introduction of CEUs as a curriculum criterion with set of conditions provided previously is to broaden the understanding and application of Chemistry Program engagement with the local chemical industry and chemistry-related labor market in general.
- Programs are expected to employ CEUs to develop and implement unique student chemistry experiences that meet the requirements and conditions of CEUs and the national trends.
- Students in CEUs activities should demonstrate and develop responsibility, ethical and scientific conduct, leadership, time management, organizational skills, engagement with literature, oral and written communication. Students also should build strong transferable skills that help them establish their professional careers in chemistry.
- CEUs are set to acknowledge individual differences, passion, and desires of different students, therefore, programs are encouraged to offer good range of CEUs activities for students to choose from and incorporate to meet the conditions of CEUs, 8 credit hours, and a minimum of 180 contact hours. [Example: if Chemistry Experience Activity is a Field experience taking place during summer vacation, then student is required to work 6 hours five days a week for the total of 6 weeks so, (6hrs×5days) ×6weeks=180hrs)].
- For the development of CEUs, programs can integrate more than one experience course in order to meet the 8 credit hours and the 180 contact hours of CEUs, and hence enrich students' work-related experiences.

b. Applied Chemistry Units:

Applied Chemistry Units are in conjunction with Chemistry Experience Units, where student incorporates a wide range of applied chemical courses in certain areas of chemical industries in addition to some technical and non-technical courses with work experience. These applied courses aim to broaden students' practical knowledge and skills that are required by the chemical industry. These courses are also used as a basis for applied chemical tracks, to enable graduates to work in a wide variety of local and national industrial sectors.

Appendix (B): Alignment of Key Learning Outcomes of Chemistry with KSA-NQF.

General Key Learning Outcomes	NQF Learning Areas		
	Knowledge and understanding	Skills	Values, Autonomy, and Responsibility
1	✓		
2	✓		
3	✓		
4		✓	
5		✓	
6		✓	
7		✓	
8		✓	
9		✓	
10			✓
11			✓
12			✓
13			✓

NQF Learning Areas	Knowledge and understanding	Practical Skills		Values, Autonomy, Responsibility
Chemistry Learning Areas	Knowledge and understanding	Laboratory Skills	Classroom Skills	Students Professional Development
Chemistry Key Learning Outcomes	**KLO1.** Demonstrate a critical understanding of the key and core knowledge of the main branches of chemistry and related fields, as outlined GKUs and SKUs. **KLO2.** Identify the interdisciplinary nature between chemistry branches to interpret and evaluate the practical applications of the essential facts, concepts, principles, and theories of chemistry. **KLO3.** Predict and interpret chemical and physical changes that organic and inorganic materials undergo using appropriate chemical information, data, and rules.	**KLO-4.** Practice health and safety regulations while handling chemicals and performing laboratory activities with the capability to conduct a sufficient risk assessment. **KLO-5.** Conduct accurate quantitative and qualitative measurements using standard chemical instrumentation and software and report experimental results with appropriate interpretation, calculations, and reasonable conclusions. **KLO-6.** Synthesize and characterize organic and inorganic materials using appropriate procedures, instrumentations, and chemical apparatus. **KLO-7.** Develop a systematic and reliable experimental record via precise observations of measurements and changes and assessment of the limit of accuracy of experimental data.	**KLO-8.** Apply principles, laws and theories of chemistry and related physical and mathematical equations to solve complex chemical problems with appropriate approximation, precision, accuracy, and statistical validity. **KLO-9.** Solve chemical problems related to different applications of chemistry through critical thinking to develop appropriate rational, explanations and answers.	**KLO-10.** Plan, execute and report project work by employing knowledge learned, practical skills developed previously in the program with effective use of chemical literature and retrieval of chemical methods. **KLO-11.** Present chemical data and reports scientifically in written and oral communication with proper scientific conduct and ethical responsibility. **KLO-12.** Lead and manage chemistry project work effectively, and demonstrate self-discipline, decision-making capabilities and Engagement in team working to build a working network in chemistry related fields. **KLO -13.** Relate the learned chemistry knowledge and skills to future career and Plan for further professional training as a chemist.

Appendix (C): Learning Outcomes and Topics for Knowledge Units

Essential Knowledge Unit (EKU): Mathematics

Description	This Essential unit aims to understand and master the essential concepts, principles, rules, and theorems of calculus I and II, common applications of differential equations, statistics topics and applications, applied Linear Algebra. It also enables students to practice analytically various calculus concepts, principles, rules, theorems, and techniques on real-life problems related to the field of chemistry. Students are also required to demonstrate how to use mathematical software and tools on various calculus, statistics, and differential equations.
Topics	**The following topics must be included in this EKU:** 1. Calculus 1 Limits and continuity of functions of a single variable. Differentiability, Techniques of differentiation. Implicit differentiation. Local extrema, first and second derivative tests for local extrema. Concavity and inflection points. Curve sketching. Applied extrema problems. The Mean Value Theorem and applications. 2. Calculus 2 Definite and indefinite integrals of functions of a single variable. Fundamental Theorem of Calculus. Techniques of integration. Hyperbolic functions. Applications of the definite integral to area, volume, arc length and surface area. Improper integrals. Sequences and series: convergence tests, integral, comparison, ratio and root tests. Alternating series. Absolute and conditional convergence. Power series. Taylor and Maclaurin series. 3. Calculus 3 Polar coordinates, polar curves, area in polar coordinates. Vectors, lines, planes, and surfaces. Cylindrical and spherical coordinates. Functions of two and three variables, limits, and continuity. Partial derivatives, directional derivatives. Extrema of functions of two variables. Double integrals, double integrals in polar coordinates. Triple integrals, triple integrals in cylindrical and spherical coordinates. 4. Introduction to Differential Equation: Techniques and applications of ordinary differential equations, including Fourier series and boundary value problems, and an introduction to partial differential equations.
Specialized Learning Outcome	**By completing this EKU, students should be able to:** 1. Recognize the essential concepts, principles, rules, and theorems of mathematics related to limits and their properties, differentiation and their applications, integration and their applications, and various types of functions. 2. Demonstrate analytically various calculus concepts, principles, rules, theorems, and techniques related to limits and continuity, differentiation and their applications, integration and their applications. 3. Apply mathematical concepts, principles, rules, techniques, and theorems to real-life problems in the fields of science and chemistry. 4. Distinguish various types of mathematical functions with applications and analyze and sketch the graphs of those functions by using graphical software. 5. Apply mathematical techniques and tools to calculate mathematical properties and manipulate mathematical data. 6. Practice ethical principles and responsibility in self-learning, problem solving, and continuing personal and professional development. 7. Practice mathematical software programs and tools on differential equations topics. 8. Practice mathematical software programs and tools on statistical data and analyze and interpret statistical graphical displays.

The Table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

SLOs	KLOs											
	KLO-K			KLO-LS				KLO-CS		KLO-SPD		
	1	2	3	4	5	6	7	9	10	11	12	13
1	✓											
2	✓	✓										
3			✓					✓	✓			
4	✓	✓						✓				
5	✓	✓						✓				
6								✓	✓	✓	✓	✓
7	✓	✓						✓	✓			
8	✓	✓						✓	✓			

Essential Knowledge Unit (EKU): Physics

Description	This essential unit aims to introduce chemistry students to the basic laws and principles of Newtonian mechanics; oscillations, waves, and wave optics, the basic laws of electricity and magnetism; geometrical optics, properties of electromagnetic fields, dipole and quadrupole fields and their interactions, chemical binding of molecules, electromagnetic properties of materials, Maxwell's equations, and properties of electromagnetic waves. It also provides students with background in Interference and diffraction, photons and matter waves, the Bohr atom, uncertainty principle, and wave mechanics.
Topics	The following topics must be included in this EKU: 1. Mechanics: Newton's Laws, work and energy, static properties and fluids, oscillations, transverse waves, systems of particles, and rotations. A calculus-based approach for chemistry major. 2. Electricity and Magnetism: Coulomb's Law, electric fields, Gauss' Law, electric potential, capacitance, circuits, magnetic forces and fields, Ampere's law, induction, electromagnetic waves, polarization, and geometrical optics. A calculus-based approach for major in chemistry. 3. Quantum Physics: Interference and diffraction, photons and matter waves, the Bohr atom, uncertainty principle, and wave mechanics. A calculus-based course for chemistry major.
Specialized Learning Outcome	By completing this EKU, students should be able to: 1. Recognize Newton's Laws, work and energy, static properties and fluids, oscillations, transverse waves, systems of particles. 2. Identify the basic principles, concepts, and laws of electricity and magnetism, and relate the fundamentals of this unit to real life applications. 3. Apply the basic principles, concepts, and laws of electricity and magnetism to a range of different problems in electromagnetism. 4. Solve vector calculus problems in electromagnetism. 5. Apply the basic principles, concepts, and laws of electricity and magnetism to a range of different problems in electromagnetism. 6. Demonstrate how to perform common electromagnetism laboratory techniques, apparatus, and tools in safe and healthy manners. 7. Apply principles of quantum mechanics to calculate observables on known wave function. 8. Analyze and interpret experimental results and develop appropriate and accurate conclusions.

The Table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓											
2	✓	✓											
3	✓	✓						✓	✓				✓
4	✓	✓						✓	✓				
5	✓	✓						✓	✓				
6				✓	✓	✓	✓						✓
7	✓	✓			✓		✓	✓	✓			✓	
8					✓	✓						✓	

Essential Knowledge Unit (EKU): Computer Programing

Description	Overview of computer hardware and software. Programming in Python with emphasis on basic program constructs: variables, assignments, expressions, decision structures, looping, functions, lists, files and exceptions; Introduction to objects and classes. Programming in C with emphasis on pointers and functions with output parameters. Simple multidisciplinary problem solving in science and chemistry in particular.
Topics	**The following topics must be included in this EKU:** 1. Overview of Computer Programming using Python 2. Variables, Strings and Arithmetic Operations 3. Selection Structures 4. Repetitions and Loop Statements 1 5. Functions 6. List, Tuples and Dictionaries 7. Files and Exceptions 8. Classes and Object Orientation 9. Introduction to C language 1 10. Pointers in C language
Specialized Learning Outcome	By **completing this EKU, students should be able to:** 1. Write python expressions. 2. Use python's control structures in problem solving. 3. Use the console and files for input/output. 4. Use python lists, tuples, and dictionaries in problem solving. 5. Develop python code to solve a specific problem. 6. Become familiar with programming constructs that are special to the C language. **The Table below shows maps the Specialized learning Outcomes for the SKU to the KLOs**

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓					✓	✓	✓				✓
2	✓	✓					✓	✓	✓				✓
3	✓	✓					✓	✓	✓				✓
4	✓	✓					✓	✓	✓				✓
5	✓	✓					✓	✓	✓				✓
6	✓	✓					✓	✓	✓				✓

General Knowledge Unit (GKU 1): General Chemistry

Description	This general unit enables student to distinguish between states of matter and their physical and chemical properties, as well as between mixtures and pure substances, define the atom, describe the arrangement of elements in the periodic table and their electronic distribution, draw Lewis structures for molecules, apply the laws of significant numbers to chemical arithmetic operations, name ionic and covalent compounds and determine their chemical formulas, Weighs chemical reactions, describes the types of chemical bonds and forces between molecules, describes and compares the basics of thermodynamics and solves applications on it, describes the basics of kinetics of chemical reactions and solves applications on it.

Specialized Knowledge Unit (SKU1.1): Principle of Inorganic Chemistry

Description	This SKU 1.1 presents the essential principles and common applications of chemistry. It introduces matter, energy, and measurement; atoms, molecules, and ions; chemical reactions and reaction stoichiometry; reactions in aqueous solution; thermochemistry; electronic structure of atoms; periodic properties of the elements; and basic concepts of chemical bonding.
Topics	**The following topics must be included in this SKU:** 1. Essential Ideas of Chemistry. 2. Atoms, Molecules, and Ions. 3. Electronic Structure and Periodic Properties. 4. Periodic table and periodicity 5. Chemical Bonding and Molecular Geometry. 6. Advanced Theories of Covalent Bonding. 7. Composition of Substances and Solutions. 8. Stoichiometry of Chemical Reactions. 9. Acid-base chemistry 10. Solubility 11. Nuclear chemistry
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Distinguish chemical and physical properties of matter and their changes, empirical formulas and molecular formulas, and molecular substances and ionic substances. 2. Describe the basics of atomic theories and models, fundamental atomic structure, the periodicity of elements in the periodic table, and the system and the surroundings in thermodynamics. 3. Apply dimensional analysis using appropriate units, significant figures, scientific notation, and the mole concept in quantitative chemical calculations. 4. Calculate atomic weight of an element, formula weights, the empirical and molecular formulas of a compound, the percent yield of a reaction, and solution concentration. 5. Identify properties of elements in the periodic table according to periodicity patterns 6. Describe fundamentals of acid/base chemistry, including pH calculations, buffer behavior, and acid/base titrations

The table below shows maps of the Specialized learning Outcomes for the SKU to the KLOS.

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓										
3	✓	✓	✓					✓	✓				✓
4								✓	✓				✓
5	✓	✓	✓										
6	✓	✓	✓										

Specialized Knowledge Unit (SKU1.2): Principle of Physical Chemistry

Description	This SKU 1.2 presents the essential principles and common applications of chemistry. It introduces the elementary principles and theories of chemistry, electronic structure of atoms, quantum mechanics and atomic orbitals; representations of orbitals, gases laws and properties, Intermolecular forces, liquids, solids, solutions, kinetics, equilibria, precipitation, thermodynamics, electrochemistry, organic chemistry,
Topics	**The following topics must be included in this SKU:** 1. Electronic structure of atoms, quantum mechanics and atomic orbitals 2. Gases laws and properties 3. Intermolecular forces, liquids, solids, solutions 4. Chemical kinetics 5. Chemical equilibria 6. Thermodynamics, 7. Electrochemistry, 8. Organic chemistry
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Relate the quantum numbers to the number and type of orbitals, 2. Determine electron configuration of atoms and ions. 3. Predict the trends in atomic radii, ionic radii, ionization energy, and electron affinity using the periodic table. 4. Apply the gas laws and kinetic molecular theory to processes involving gases. 5. Interpret and sketch phase diagrams and calculate the empirical formula and density of ionic and metallic solids. 6. Determine rate law, rate constant, order, and the concentration of reactants at a given time for a chemical reaction; and 7. predict a rate law for a reaction having a multistep mechanism. 8. Explain fundamental thermodynamic properties by applying thermodynamic laws **The table below shows maps of the Specialized learning Outcomes for the SKU to the KLOS.**

SLOs	KLOs												
	KLO-K				KLO-LS			KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓										
3	✓	✓	✓					✓	✓				✓
4								✓	✓				✓
5	✓	✓	✓										
6	✓	✓	✓										
7	✓	✓	✓					✓	✓				✓
8	✓	✓	✓					✓	✓				✓

Specialized Knowledge Unit (SKU1.3): General Chemistry Laboratory

Description	SKU 1.3 presents complements and consolidates the theoretical knowledge acquired general chemistry units. In addition, this specialized practical unit offers an opportunity to investigate chemical concepts in an experimental setting according to the chemistry laboratory health and safety regulations. Areas of experimentations include molecular geometry and bonding theories, gases, liquids, solids, solutions, chemical kinetics, chemical equilibrium, and chemical thermodynamics.
Topics	**The following topics must be included in this SKU:** 1. Laboratory Safety and Work Instructions; Common Laboratory Apparatus; Basic Laboratory Techniques 2. Molecular Geometries of Covalent Molecules: Lewis Structures and the VSEPR Model 3. Behavior of Gases: Molar Mass of a Vapor 4. Determination of R: The Gas Law Constant 5. Enthalpy of Vaporization and Clausius-Clapeyron Equation 6. Crystalline Solids 7. Freezing Point Depression 8. Rates of Chemical Reactions I: A Clock Reaction 9. Rates of Chemical Reactions II: Rate and Order of H2O2 Decomposition 10. Colorimetric Determination of an Equilibrium Constant in Aqueous Solution 11. Chemical Equilibrium: Le Châtelier's Principles 12. Determination of the Dissociation Constant of a Weak Acid 13. Titration of Acids and Bases 14. Hydrolysis of Salts and pH of Buffer Solutions 15. Solubility and Thermodynamics
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Practice basic laboratory safety and work instructions in general chemistry laboratories. 2. Record experimental results neatly and concisely in a laboratory notebook and in a manner that gives proper attention to sources of experimental error. 3. Analyze and interpret experimental results, use a spreadsheet program such as Excel, and develop appropriate and accurate conclusions. 4. Demonstrate laboratory proficiency by supporting arguments with evidence, and by clearly communicating the results of the chemical experiments. 5. Perform precise quantitative measurements using volumetric glassware, analytical balances, and electrochemical and spectroscopic instruments. **The table below shows maps of the Specialized learning Outcomes for the SKU to the KLOS.**

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1			✓	✓									✓
2				✓	✓		✓				✓		✓
3					✓		✓					✓	
4										✓	✓	✓	✓
5					✓	✓							

General Knowledge Unit (GKU 2): Organic Chemistry

Description	Describe the carbon element and its derivative compounds and their structures and learn about their properties and how the carbon element bonds to itself and other elements to form compounds, heterogeneous rings and vital organic molecules, study their interactions and suggest an appropriate mechanism for them, in addition to analyzing the organic molecules in terms of their photosynthetic activity and their stereochemistry and using different spectrophotometric methods to deduce structural formulas of organic molecules.

Specialized Knowledge Unit (SKU2.1): Principle of Organic Chemistry

Description	This unit covers an Introduction to organic chemistry including definition of organic chemistry, importance and general properties of organic compounds, chemical bonding and hybridization, bonds polarity, classification of hydrocarbons, saturated hydrocarbons, unsaturated hydrocarbons, their physical properties, preparation, and reactions. Aromatic compounds, aromaticity and Huckel rule. Nomenclature of aromatic compounds. Electrophilic substitution reactions of aromatic compounds and their mechanism. Reactions of side chain. Stereochemistry. Alcohol, phenols ethers, aldehydes, ketones, carboxylic acids and derivatives and amines. Their physical properties, acidities, solubility, preparations, and reactions. Nucleophilic addition to carbonyl group. Application of organic compounds in industrial and medical fields.
Topics	**The following topics must be included in this SKU:** 1. Introduction to organic chemistry which includes definition of organic chemistry, importance and general properties of organic compounds, chemical bonding and hybridization, bonds polarity, classification of hydrocarbons. 2. Alkanes: Nomenclature (IUPAC and trivial), properties, synthesis, and reactions. 3. Alkenes: Nomenclature, properties, synthesis, and reactions including polymerization of Olefins. 4. Stereochemistry: Introduction to stereochemistry including conformational, geometrical, and optical isomers. 5. Alkynes: Nomenclature, properties, synthesis and reactions. 6. Aromatic compounds.: Aromaticity, Hükel rule, Nomenclature, Electrophilic aromatic substitution reactions, Side halogenations and oxidation. Orientation in mono-substituted benzene derivatives. 7. Functional groups (Alcohols, phenols, ethers, carbonyl group derivatives and amines), Nomenclature, properties, synthesis, and reactions including nucleophilic addition to Carbonyl group and its mechanism. 8. Examples of multi-step synthesis. 9. Examples of organic compounds applications to various industrial and biological processes
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Differentiate between different types of carbon atom hybridizations and compounds and functional groups derived from them. 2. Apply IUPAC rules in writing names and drawing structures of classes of organic compounds. 3. Identify and classify physical and chemical properties of major functional groups. 4. Apply basic organic reactions for the preparation of hydrocarbons and common functional groups. 5. Outline schemes including multistep reactions. 6. Interpret and draw stereochemistry of selected examples of organic reactions.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓						✓	✓		✓	
2	✓							✓	✓				
3	✓	✓	✓					✓					
4	✓	✓	✓					✓	✓	✓			
5	✓	✓	✓					✓	✓				
6	✓	✓						✓	✓				

Specialized Knowledge Unit (SKU2.2): Organo-Physical Chemistry

Description

This organo-physical unit includes two main topics organic reactions and mechanisms and organic spectroscopy. The reaction and mechanism part covers the different types of reactions, such as: Substitution and elimination reactions in saturated hydrocarbons, electrophilic addition to unsaturated hydrocarbons, nucleophilic addition to carbonyl group, pericyclic reactions, and the detailed description of mechanisms of these reactions. The organic spectroscopy part includes IR, 1H, 13C-NMR, MS, UV-Vis the bases of these techniques and their applications in the identifications of structures of organic reactions.

Topics

The following topics must be included in this SKU:

1. Introduction, Thermodynamic and Activation energy. Physical and chemical methods for the identification of reaction mechanism.
2. Reaction kinetics and mechanism, isotope effect labeling and intermediates determinations.
3. Acids and bases,
4. Aliphatic nucleophilic substitution reactions
5. Addition and elimination reactions
6. Nucleophilic addition to carbonyl group
7. Pericyclic reactions
8. Radical reactions and photochemistry
9. Mechanisms involved in these reactions, such as SN1, SN2, E1, E2 etc..
10. Application of spectroscopic techniques (NMR, IR, UV-Vis, MS) for the identification of organic reactions products.

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Categorize reaction mechanisms, kinetic and thermodynamic considerations.
2. Describe reaction intermediate, medium effect and controlled reactions.
3. Identify methods used for the investigation of reaction mechanisms, energy considerations and stereochemical considerations.
4. Recognize and characterize types of reaction mechanism and illustrate principles of molecular rearrangements and structure-reactivity.
5. Explain the use of isotopes in elucidating reaction mechanisms.
6. Compare and distinguish reactivity based on physical and chemical properties of the molecular structure.
7. Apply reaction mechanisms, stereochemistry, and kinetics in the identification of structures of organic compounds.
8. Discuss principles of spectroscopy, their types and differences between them.
9. List areas of application of different spectroscopic techniques.
10. Apply different spectral techniques in solving spectral problems and identification of reaction products.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓						✓	✓		✓	
2	✓							✓	✓				
3	✓	✓	✓					✓					
4	✓	✓	✓					✓	✓	✓			
5	✓	✓	✓					✓	✓				
6	✓	✓						✓	✓				
7	✓	✓	✓						✓	✓		✓	
8	✓							✓	✓			✓	
9	✓	✓	✓					✓				✓	
10	✓	✓	✓					✓	✓	✓		✓	

Specialized Knowledge Unit (SKU2.3): Bioorganic Chemistry

Description

Heterocycles, Nomenclature, Aromaticity, Five, six and seven membered heterocyclic compounds: Synthesis, Reactions, Cycloaddition Reactions, biological activity, antibiotics, antitumor. Biologically important Heterocycles: Uracil and Purines. Carbohydrates, Definition, Nomenclature, Classification, absolute configuration, cyclic structures, oxidation, reduction, osazones, ascorbic acid, amino sugars. Amino acids, Proteins, Natural amino acids: Properties, Synthesis and Reactions, Synthesis of Peptides, Protein classification. Lipids, Classification, Waxes, Oils and Fats (Glycerides), synthesis and properties of Glycerides, Glycolipid. Natural products, primary and secondary metabolites, isolation, separation, and structural identification. Isoprenoids: Terpenes, classification, monoterpenes and sesquiterpenes. Steroids: Triterpenoids and Sterols, Cardenolides, Biosynthesis of Terpenoids and Steroids (Acetate Pathway). Alkaloids, Classification, Examples: Pyrrolidines, Piperidenes, Isoquinolines, Quinolines, Indoles and Purines. Biosynthesis of Alkaloids (Amino acid Pathway). Alkaloids, Examples: Flavonoids, Anthraquinones, Coumarins, Xanthones, and Polyketide pathway. Biologically important natural products

Topics

The following topics must be included in this SKU:

1. Heterocyclic compounds, classifications, aromaticity
2. Five, six and seven membered heterocycles.
3. Pyrrole, furan, thiophene, imidazole, pyrazole, indole, pyridine, quinoline, isoquinoline.
4. IUPAC and trivial names.
5. Synthesis, reactions, electrophilic and nucleophilic substitutions, physical properties, and biological activity. Uracil and purines.
6. Carbohydrates, definition, nomenclature, classification.
7. Glyceraldehyde, monosaccharides, oligosaccharides, polysaccharides.
8. Absolute configuration, A, L-configuration, chiral centers, asymmetric carbon, optical activity.
9. Fischer, Haworth projections, cyclic structures, α, β-configuration. Oxidation, reduction.
10. Amino acids, classification, nomenclature, structures.
11. Peptides, proteins, lipids, structures biological importance.
12. Natural products, primary and secondary metabolites, classification.
13. Isoprenoid, monoterpenoids, sesquiterpenoids, diterpenoids, steroids.
14. Biosynthesis.
15. Flavonoids, coumarins, alkaloids, structures names and classification.
16. Important natural products, use in industrial and medical fields.

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Classify different classes of heterocyclic compounds.
2. Write IUPAC and trivial names and draw structures of examples of heterocycles.
3. List examples of biological and industrial applications of specific examples of heterocyclic compounds.
4. Define carbohydrates and their general structures and recognize different types of carbohydrates.
5. Apply stereochemistry principles in drawing structures of carbohydrates.
6. Categorize amino acids, their stereochemistry, and structures.
7. Define proteins and peptides, their structures and biological importance.
8. Define natural products, primary and secondary metabolites.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

LOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓						✓	✓		✓	
2	✓							✓	✓				
3	✓	✓	✓					✓					
4	✓	✓	✓					✓	✓	✓			
5	✓	✓	✓					✓	✓				
6	✓	✓						✓	✓				
7	✓	✓	✓						✓	✓			
8	✓							✓	✓				

Specialized Knowledge Unit (SKU2.4): Organic Chemistry Laboratory

Description

This unit covers all aspects related to working in organic chemistry lab from the basic requirements such as safety of chemicals, getting familiar to different laboratory equipment and understanding of different warning and safety signs when working in chemistry lab. It covers topics such as Solubility, Extraction, Distillation. Identification of physical constants such as melting and boiling points. Chromatography: Paper (PC), Column (CC), Thin layer Chromatography (TLC). Tests for the identification of Alkane, Alkene, Aromatic, Organic halides, Hydroxy-Compounds, Nitro and amine compounds, Aldehydes and Ketones, Carbohydrate, Carboxylic acids, and their derivatives. Elemental Analysis.
Techniques of organic chemistry; preparation, properties of typical organic compounds; separation, purification, analysis, and characterization of organic compounds.
Synthesis of significant types of organic compounds and study of their properties; laboratory separations of mixtures of organic substances, instrumental methods of separation, identification, and analysis. Isolation and Identification of Natural Products, using TLC and CC in purification of organic compounds. Writing reports for unknown organic compounds.

Topics

The following topics must be included in this SKU:

1. Laboratory Safety
2. Techniques and Apparatus
3. Purification of Solid and Liquid compounds
4. Extraction, Chromatography, Column chromatography, Thin Layer Chromatography
5. Identification of Organic Compounds
6. Qualitative Identification of Organic Compounds
7. Spectral Methods
8. Kinetic and Theromodynamics control organic reactions.
9. Multistep Organic Synthesis
10. Polymer
11. Carbohydrates

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Perform common laboratory techniques including thin-layer chromatography, refractive index, simple distillation, fractional distillation, solvent extraction, collection or control of gaseous products, crystallization, and sublimation.
2. Synthesize and isolate and characterize, at the microscale level, the product(s) of simple organic reactions.
3. Record experimental results neatly and concisely in a laboratory notebook and in a manner that gives proper attention to sources of experimental error.
4. Illustrate the outcome and mechanism of organic reactions under investigation.
5. Analyze and interpret experimental results and develop appropriate and accurate conclusions.
6. Differentiate between the biochemical tests of the different biomolecules.
7. Practice laboratory safety and work instructions for organic chemistry laboratories.
8. Use common experimental biological chemistry techniques and instruments.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLOs

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓			✓	✓	✓			✓			
2	✓	✓				✓			✓	✓	✓		
3					✓	✓	✓			✓	✓	✓	
4	✓						✓	✓	✓				
5	✓						✓	✓	✓				
6					✓		✓	✓	✓				
7				✓									✓
8	✓	✓		✓	✓	✓	✓					✓	✓

General Knowledge Unit (3): Physical Chemistry

Description	The Physical chemistry Knowledge Unit establishes and develops understanding of the physical properties of bulk matter at macroscopic. It describes classical thermodynamic properties of chemical systems and how chemical reactions occur. It also covers various physical processes that chemical reactions undergo such as chemical equilibria, chemical kinetics, and catalysis. In addition, the structures of and properties of individual atoms and molecules use quantum mechanics. Therefore, the unit introduces the essential principles and common applications of quantum chemistry and spectroscopy. The field of quantum chemistry and spectroscopy emphasizes analyzing and describing the structures of individual atoms and molecules as well as calculating their properties. offers an opportunity to investigate chemical concepts in an experimental setting according to the physical chemistry laboratory health and safety regulations. In addition, it focuses on teaching common physical chemistry laboratory techniques and instruments.

Specialized Knowledge Unit (3.1): Physical Chemistry of Bulk Matter

Description	Unit 3.1 introduces the essential principles and common applications of classical thermodynamics and statistical thermodynamics. Thermodynamics provides a description of matter and the transformation between different forms of energy on a macroscopic scale using bulk properties such as pressure, density, volume, and temperature. On the other hand, statistical thermodynamics provides a description of classical thermodynamics on a microscopic scale (atoms and molecules) using probability theory. Ranges of physical chemistry properties are also explored such as Chemical Equilibrium, The Properties of Real Gases, Phase Diagrams and the Relative Stability of Solids, Liquids, and Gases, Ideal and Real Solutions, Electrolyte Solution.
Topics	The following topics must be included in this SKU: 1. Fundamental Concepts of Thermodynamics 2. Heat, Work, Internal Energy, Enthalpy, and the First Law of Thermodynamics 3. State Functions: Internal Energy and Enthalpy 4. Thermochemistry, Entropy and the Second and Third Laws of Thermodynamics 5. Chemical Equilibrium 6. The Properties of Real Gases 7. Phase Diagrams and the Relative Stability of Solids, Liquids, and Gases 8. Ideal and Real Solutions, Electrolyte Solutions 9. Electrochemistry 10. Probability, The Boltzmann Distribution 11. Ensemble and Molecular Partition Functions 12. Surface Chemistry 13. Chemical Kinetics and Catalysis
Specialized Learning Outcome	By completing this SKU, students should be able to: 1. Define laws and fundamental concepts of classical thermodynamics, statistical thermodynamics, chemical equilibria, chemical kinetics, and catalysis, and summarize the real-life applications related to these topics. 2. Analyze, interpret, and predict the behavior and macroscopic properties of chemical and physical processes as well as ideal and real gases. 3. Calculate, relate, and predict equilibrium and spontaneity of chemical reactions in addition to rate laws and reaction orders. 4. Sketch, illustrate, and describe phase diagrams and relative stability of solids, liquids, and gases as pure substances and as mixtures. 5. Relate macroscopic thermodynamic properties to microscopic states; and apply probability principles to the ensembles of atoms or molecules and use the probability outcomes to predict thermodynamic properties of the system. 6. Apply mathematical and statistical techniques to calculate physical and chemical properties related to chemical systems.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓					✓	✓		✓	✓	
3	✓	✓						✓	✓		✓	✓	
4	✓	✓									✓	✓	
5	✓	✓									✓	✓	
6	✓	✓						✓	✓		✓	✓	

Specialized Knowledge Unit (3.2): Physical Chemistry of Microscopic Matter

Description	Unit 3.2 is an introduction to theoretical chemistry. It introduces the essential principles and common applications of quantum chemistry and spectroscopy. The field of quantum chemistry and spectroscopy emphasizes analyzing and describing the structures of individual atoms and molecules as well as calculating their properties. This course connects physical chemistry concepts to the real world by covering three basic types of motion for individual atoms and molecules: translation, vibration, and rotation; consequently, the translational, vibrational, and rotational spectra can be analyzed and interpreted. Moreover, other possible applications include scanning tunneling microscope, atomic force microscope, tunneling in chemical reactions, quantum wells, quantum dots, teleportation, quantum computers, computational chemistry, and others.
Topics	**The following topics must be included in this SKU:** 1. From Classical to Quantum Mechanics 2. The Schrödinger Equation 3. The Quantum Mechanical Postulates 4. Using Quantum Mechanics on Simple Systems 5. The Particle in the Box and the Real World 6. Commuting and Noncommuting Operators and the Surprising Consequences of Entanglement 7. A Quantum Mechanical Model for the Vibration and Rotation of Molecules 8. The Vibrational and Rotational Spectroscopy of Diatomic Molecules 9. The Hydrogen Atom 10. Many-Electron Atoms 11. Quantum States for Many-Electron Atoms and Atomic Spectroscopy 12. The Chemical Bond in Diatomic Molecules 13. Computational Chemistry 14. Molecular Symmetry 15. Molecular Structure and Energy Levels for Polyatomic Molecules 16. Electronic Spectroscopy 17. Nuclear Magnetic Resonance Spectroscopy
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Identify the principles and fundamental concepts of quantum chemistry and spectroscopy and summarize the real-life applications related to SKU. 2. Apply the Schrödinger equation to simple chemical systems that model the translational, vibrational, and rotational motions; and analyze and interpret the calculated energies and wave functions. 3. Calculate and predict observables of physical and chemical systems including probability, expectation value, and eigenvalues. 4. Predict and describe the electronic structures of hydrogen-like atoms, many-electron atoms, and molecules, and use localized and delocalized bonding models to describe chemical bonding. 5. Predict the structure and energy levels of small molecules via computational chemistry. 6. Apply mathematical and statistical techniques to calculate physical and chemical properties related to chemical systems. **The table below shows maps the Specialized learning Outcomes for the SKU to the KLO**

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓					✓	✓		✓	✓	
3	✓	✓						✓	✓		✓	✓	
4	✓	✓									✓	✓	
5	✓	✓									✓	✓	
6	✓	✓						✓	✓		✓	✓	

Specialized Knowledge Unit (3.3): Physical Chemistry of Laboratory

Description	This specialized unit (3.3) complements and consolidates the theoretical knowledge acquired in physical chemistry courses. It offers an opportunity to investigate chemical concepts in an experimental setting according to the physical chemistry laboratory health and safety regulations. In addition, it focuses on teaching common physical chemistry laboratory techniques and instruments. Areas of experimentations include practices in classical thermodynamics, statistical thermodynamics, kinetics, quantum chemistry, spectroscopy, and computational chemistry
Topics	**The following topics must be included in this SKU, however, the** 8 primary themes, with each theme encompassing 3 to 5 general topics. It is required to include a minimum of two topics from each theme. **1- Thermodynamics:** 1. Measurement of Heat Capacities of Solids and Liquids 2. Determination of Enthalpy Changes in Chemical Reactions 3. Investigation of Phase Transitions and Equilibrium Constants 4. Study of Colligative Properties of Solutions 5. Determination of Gibbs Free Energy Change of Chemical Reactions **2- Statistical Thermodynamics:** 1. Measurement of Boltzmann Constant using Brownian Motion 2. Analysis of Distribution Functions in Gases 3. Evaluation of Entropy Change in Phase Transitions 4. Investigation of Maxwell-Boltzmann Distribution Law 5. Study of Partition Functions and Thermodynamic Properties **3- Chemical Kinetics:** 1. Determination of Reaction Rate Constants using spectroscopic techniques 2. Investigation of Factors Affecting Reaction Rates and determination of reaction order using Polari-metric, electrochemical or conducti-metric techniques 3. Study of Reaction Mechanisms using Spectroscopic Techniques 4. Measurement of Activation Energies using Arrhenius Equation 4- **Quantum Chemistry:** 1. Calculation of Molecular Orbital Energies using Computational Methods 2. Analysis of Electronic Spectra and Molecular Energy Levels 3. Study of Electronic Structure and Bonding in Molecules 4. Investigation of Vibrational and Rotational Energy Levels 5. Determination of Transition Probabilities in Electronic Transitions 5- **Molecular Spectroscopy:** 1. Analysis of Infrared Spectra for Molecular Identification 2. Measurement of UV-Visible Absorption Spectra 3. Investigation of Raman Scattering in Molecules 4. Study of Nuclear Magnetic Resonance (NMR) Spectroscopy 5. Determination of Electronic and Vibrational Energy Levels **6- Phase Rule:** 1. Determination of Phase Diagrams and analysis of Solid Solutions and Phase Transformations 2. Study of Phase Equilibria and determination of Critical Points 3. Investigation of Eutectic and Peritectic Reactions **7- Electrochemistry:** 1. Measurement of Standard Electrode Potentials and the effect of temperature 2. Electroplating & Determination of Faraday's Constant 3. Fuel Cell Operation **8- Surface and Catalysis:** 1. Adsorption Isotherms 2. Catalytic Activity Measurements 3. Determination of Surface Area and Pore Size Distribution

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Practice laboratory safety and work instructions in physical chemistry laboratories.
2. Record experimental results neatly and concisely in a laboratory notebook and in a manner that gives proper attention to sources of experimental error.
3. Apply essential principles and concepts taught in classical thermodynamics, statistical thermodynamics, kinetics, quantum chemistry, and spectroscopy to laboratory measurements.
4. Demonstrate how to use common experimental physical chemistry techniques and instruments.
5. Perform computational chemistry calculations and compare their results with the collected experimental data.
6. Calculate chemical properties extracted from experimental data and apply mathematical and statistical techniques.
7. Utilize data analysis software to analyize and interpret experimental data in physical chemistry.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓			✓	✓	✓			✓				
2	✓				✓			✓	✓	✓			
3				✓	✓	✓			✓	✓	✓		
4						✓	✓	✓					
5						✓	✓	✓					
6				✓		✓	✓	✓					
7				✓		✓	✓	✓					

General Knowledge Unit (4): Inorganic Chemistry

Description	It covers a wide range of topics in inorganic chemistry, including atomic structure and bonding, symmetry and group theory, molecular orbitals, acid-base and donor-acceptor chemistry, coordination chemistry, theories and experimental evidence of electronic structure, reactions and mechanisms, physical techniques in inorganic chemistry, organometallic chemistry, bonding, reactions, and applications to catalysis, solid state chemistry, classification of materials, modern methods of synthesis and fabrication, as well as characterization and applications of materials

Specialized Knowledge Unit (4.1): Bonding theories and Molecular structure

Description

This Unit expands the discussion of different Bonding theories which can be used to describe bonding in molecules. The Unit starts from simple bonding theory to more complex bonding theories such symmetry and group theory, molecular orbitals. The unit also covers acid-base and acceptor -donor chemistry.

Topics

The following topics must be included in this SKU:

1. Atomic Structure
2. Simple Bonding Theory
3. Symmetry and Group Theory
4. Molecular Orbitals
5. Acid-Base and Donor-Acceptor Chemistry

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Provide an overview of the fundamental concepts of inorganic chemistry.
2. Explain the atomic structure based on quantum mechanics and explain periodic properties of the atoms.
3. Describe the structure and bonding in molecules based on bonding theories.
4. Predict the types and structure of bonding of molecules / ions using bonding theories.
5. Differentiate between acids / bases and predict the reactions between acids and bases.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓					✓	✓		✓	✓	
3	✓	✓						✓	✓		✓	✓	
4	✓	✓									✓	✓	
5	✓	✓									✓	✓	

Specialized Knowledge Unit (4.2): Chemistry of elements

Description	This unit introduces solid-state chemistry, physical and chemical properties of a macroscopic crystal, properties of bulk materials compared to small molecules. The unit also describes the chemical and physical properties of main groups elements, groups of transition elements, coordination chemistry, electronic spectra in coordination compounds.
Topics	**The following topics must be included in this SKU:** 1. The crystalline solid state 2. Chemistry of the main group elements 3. Chemistry of Transition elements 4. Physical techniques in inorganic chemistry
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Define the fundamental principles and concepts of inorganic chemistry and summarize the real-life applications related to this course. 2. Describe the basic principles of nonmetals, transition metals, and coordination chemistry. 3. Apply the basic principles of periodic law to predict the reactivity, physical and chemical properties, and compounds of groups 14–18, d-block, and f-block elements of the periodic table. 4. Examine the structures of solid states. 5. Categorize materials based on their chemical bonding, structure, and properties. 6. Analyze characterization technique data to evaluate materials.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓					✓	✓		✓	✓	
3	✓	✓						✓	✓		✓	✓	
4	✓	✓									✓	✓	
5	✓	✓									✓	✓	
6	✓	✓									✓	✓	

Specialized Knowledge Unit (4.3): Chemistry of inorganic materials

Description

This unit is concerned with the properties and behavior of inorganic compounds, which include metals, minerals, and coordination compounds, organometallic compounds, and their physical and chemical properties. The unit also emphasizes the applications of inorganic materials as catalysts, pigments, coatings, surfactants, medicines, fuels.

Topics

The following topics must be included in this SKU:

1. Coordination Chemistry Structures and Isomers, Bonding, Electronic Spectra, and Reactions and Mechanisms
2. Physical techniques in inorganic chemistry
3. Transition metal organometallic chemistry, bonding, and reactions
4. Organometallic reactions and catalysis
5. Nanomaterials
6. Materials Characterization

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Name coordination compounds and draw their structures.
2. Explain the diverse coordination numbers and isomerism in coordination compounds.
3. Discuss the bonding in organometallic compounds of transition metals.
4. Explore modern techniques for material synthesis and fabrication.
5. Categorize materials based on their chemical bonding, structure, and properties.
6. Analyze characterization technique data to evaluate materials.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓										
2	✓	✓	✓					✓	✓		✓	✓	
3	✓	✓						✓	✓		✓	✓	
4	✓	✓									✓	✓	
5	✓	✓									✓	✓	
6	✓	✓									✓	✓	

Specialized Knowledge Unit (4.4): Inorganic Chemistry Laboratory

Description

This unit aims to develop inorganic chemistry laboratory skills such as analyzing experimental results and writing laboratory reports in a scientific way, practice common inorganic chemistry laboratory techniques and fundamental inorganic concepts. In addition, it focuses on teaching common inorganic chemistry laboratory techniques and glassware; synthesizing and isolating inorganic compounds; utilizing a variety of analytical characterization techniques; and incorporating fundamental inorganic chemistry information from textbooks, reference works, and peer-reviewed journals.

Topics

The following topics should be included in this SKU:

1. Introduction and Check-In; Laboratory Safety; Laboratory Reports
2. Preparation of inorganic compounds
3. Identification of geometrical isomerism using Infrared Spectroscopy
4. Studying inorganic compounds structures using NMR spectra.
5. Identification of the physical properties of synthesized inorganic compounds.
6. Studying the novel synthetic techniques including high-temperature synthesis, air-free synthesis using a vacuum line, and synthesis in unusual solvent systems.
7. Transition metal catalysis.
8. Identifying the of reaction Kinetics
9. Identifying the electronic properties of transition metal complex using UV/Vis and EPR techniques.
10. Studying the magnetic Properties of inorganic compounds.
11. Preparation and structure of different metal complexes and organometallic compounds
12. Molecular Orbital Calculations of Inorganic Compounds
13. Characterization of solid-state compounds by UV-visible absorption, infrared, and x-ray diffraction.

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Demonstrate how to perform common solid-state techniques to synthesize inorganic compounds.
2. Synthesize, isolate, characterize, and explain the properties of main group, coordination, and organometallic compounds.
3. Record experimental results neatly and concisely in a laboratory notebook and in a manner that gives proper attention to sources of experimental error.
4. Analyze and interpret experimental results and develop appropriate and accurate conclusions.
5. Work effectively as an individual and in groups and to practice leadership when conducting inorganic experiments and report and communicating results.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓			✓	✓	✓			✓			
2	✓	✓				✓			✓	✓	✓		
3					✓	✓	✓			✓	✓	✓	
4	✓						✓	✓	✓		✓	✓	
5	✓						✓	✓	✓		✓	✓	

General Knowledge Unit (5): Analytical Chemistry

Description	This GKU covers the full scenario of typical chemical analysis methods, starting from selecting the appropriate analytical method and ending with reporting the analytical results. The scenario covers either quantitative analysis or qualitative analyses or both. Both kinds of analysis could include classical and instrumental analysis. The frontal involves volumetric and gravimetric analyses, while the latter involves spectroscopic analysis, separation-based analysis, and electroanalysis.

Specialized Knowledge Unit (5.1): General concepts in analytical chemistry

Description	This Unit presents in brief the essential principles and common applications of all qualitative and quantitative method in analytical chemistry. It focuses on selection of appropriate analytical methods sampling, sample preparation, preparation of different kinds of solutions, data analysis, and writing reports. This unit also covers errors in analytical chemistry, quality of chemical analysis, and evaluation of analytical results.
Topics	**The following topics must be included in this SKU:** 1. Definition of Analytical Chemistry along with its role in All Basic and Applied Sciences? Qualitative and Quantitative Analysis 2. Basic Tools and Operations of Analytical Chemistry 3. Statistics and Data Handling in Analytical Chemistry 4. Good Laboratory Practice: Quality Assurance and Method Validation 5. Stoichiometric Calculations: The Workhorse of the Analyst 6. General Concepts of Chemical Equilibrium: Acid–Base Equilibria
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Outline the steps commonly employed in analytical procedures, sample treatment, and method validation. 2. Recall the concepts of topics related to chemical analysis including types of chemical reactions, equilibrium, dissociation, buffers, and indicators. 3. Suggest appropriate methods for chemical analysis. 4. Use spreadsheets for performing statistical analysis and plotting calibration and titration curves. 5. Express analytical results using appropriate units of concentrations and statistical forms. 6. Calculate analytical figures (e.g., weights, volumes, concentrations, constants, etc.), and practice the use of significant figures in handling data of chemical analysis.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓							✓	✓		
2	✓	✓	✓							✓	✓		
3	✓	✓	✓							✓	✓		
4	✓	✓								✓	✓	✓	✓
5	✓	✓						✓	✓	✓	✓	✓	✓
6	✓	✓						✓	✓	✓	✓	✓	

Specialized Knowledge Unit (5.2): Classical analytical chemistry

Description	This Unit presents in brief the classical analytical methods including both volumetric and gravimetric analyses. In particular, the volumetric analysis includes acid-base titration, complexometric titration, and precipitation titration.
Topics	**The following topics must be included in this SKU:** 1. Acid–base titrations 2. Complexometric reactions and titrations 3. Gravimetric analysis and precipitation equilibria 4. Precipitation reactions and titrations
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Recognize the fundamentals of titrations and precipitation equilibria. 2. Recall various applications of acid–base titrations, complexometric reactions, and precipitation titrations. 3. Apply calculations for titrations and precipitation equilibria. **The table below shows maps the Specialized learning Outcomes for the SKU to the KLO**

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓							✓	✓		
2	✓	✓	✓							✓	✓		
3	✓	✓	✓							✓	✓		

Specialized Knowledge Unit (5.3): Instrumental analytical chemistry

Description	This Unit presents in brief the instrumental analytical methods including spectroscopic analysis, separation-based analysis, and electroanalytical based analysis. Both direct and indirect analysis are involved in this unit.
Topics	**The following topics must be included in this SKU:** 1. Principles of Spectrometric Analytical Methods 2. Atomic Spectrometric Analytical Methods 3. Molecular Spectrometric Analytical Methods 4. Sample Preparation: Solvent and Solid-Phase Extraction 5. Principles of Chromatographic Methods 6. Gas Chromatographic Methods with Different Detectors 7. Liquid Chromatographic Methods with Different Detectors 8. Electrophoresis Methods with Different Detectors 9. Electrochemical Cells 10. Principles of Electroanalytical Methods 11. Potentiometric Methods and Electrodes 12. Voltametric Methods
Specialized Learning Outcome	**By completing this SKU, students should be able to:** 1. Recognize the essential theoretical concepts of spectroscopic, chromatographic, and electrochemical methods of analyses. 2. Discuss the functions of devices of instruments for chemical analysis. 3. Outline the potentials, limitations, and applications of instrumental analytical techniques. 4. Suggest appropriate instrumental methods for chemical analysis. 5. Solve analytical problems in spectroscopic, chromatographic, and electrochemical methods of analyses. 6. Use spreadsheets for calculating equations and analytical figures of merits of instrumental analysis and plotting various kinds of curves.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓	✓							✓	✓		
2	✓	✓	✓							✓	✓		
3	✓	✓	✓							✓	✓		
4	✓	✓								✓	✓	✓	✓
5	✓	✓						✓	✓	✓	✓	✓	✓
6	✓	✓						✓	✓	✓	✓	✓	

Specialized Knowledge Unit (5.3): Analytical Chemistry Laboratory

Description

This Unit introduces experimental applications to Analytical Chemistry. Examples of standard methods are presented to cover the analytical methods of titrations (acid-base, complexometric, precipitation, and redox), gravimetry and potentiometry. It also introduces the experimental applications taught in Instrumental Analytical Chemistry. It trains students on various types of instrumental analysis methods including spectrophotometry, atomic absorption spectroscopy (AAS), and atomic emission spectroscopy (AES); and on different separation techniques, such as, thin layer chromatography (TLC), gas chromatography (GC), high performance liquid chromatography (HPLC), and electrophoresis.

Topics

The following topics must be included in this SKU:

1. Laboratory safety in analytical chemistry
2. Basic tools and operations of analytical chemistry
3. Neutralization, redox, complexation, and precipitation titrations
4. Gravimetric analysis
5. Direct and indirect electroanalytical methods
6. Direct and indirect spectrophotometric methods
7. Infrared determination methods
8. Fluorometric determination methods
9. Flame emission spectrometric methods
10. Atomic absorption spectrometric methods
11. Inductively coupled plasma spectrometric methods
12. Sample treatment methods (digestion, liquid-liquid extraction, solid-phase extraction)
13. Thin-layer chromatographic methods
14. Gas chromatographic methods
15. Liquid chromatographic methods

Specialized Learning Outcome

By completing this SKU, students should be able to:

1. Explain the theoretical background related to experiments of volumetric, gravimetric, and potentiometric analyses.
2. Practice handling the basic and advance tools as well as operations in analytical chemistry.
3. Prepare standard solutions and reagents for spectroscopic and chromatographic analyses.
4. Carry out experiments on volumetric, gravimetric, and potentiometric analyses.
5. Carry out experiments using spectroscopic and chromatographic techniques.
6. Write up technical reports using standardized forms.

The table below shows maps the Specialized learning Outcomes for the SKU to the KLO

SLOs	KLOs												
	KLO-K			KLO-LS				KLO-CS		KLO-SPD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	✓	✓			✓	✓	✓			✓			✓
2	✓	✓				✓			✓	✓	✓		✓
3					✓	✓	✓			✓	✓		
4	✓						✓	✓	✓				✓
5	✓						✓	✓	✓			✓	✓
6					✓		✓	✓	✓			✓	

Appendix (D): Employment sectors for chemists

Chemistry programs provide professional chemists who can work in many government and industrial sectors, which could be classified in terms of their products and work nature, as shown the list below:
List of the employment sectors for chemists

- Research and development
- Energy, petroleum, and petrochemical industries
- Laboratories for standards, metrology, and quality
- Materials (cement, fertilizer, alloys, ...)
- Water & Environment
- Forensic chemistry
- Health (medical, pharmaceutical, ...)
- Agricultural and Crop Sciences
- Education & academia
- Military & public security
- Military industries
- Food industry
- Paints and pigments
- Textiles

The typical work duties for chemists in government and industrial organizations are:

- Research or/and development activities
- Leadership and management
- Simple to complex routine analysis (Quality Control Analysis)
- Production
- Teaching and training
- Supervision and evaluation
- Sales and marketing

When examining the abovementioned duties of chemists in their career, we can obtain the vital transferrable skills which chemistry programs should adopt to increase the employability of chemistry graduates. These skills are as follows:

1. Scientific & technical knowledge
2. Numeracy and problem solving
3. Information technology
4. Communications (written, oral)
5. Project management
6. Teamwork
7. Leadership
8. Laboratory skills with ethical & scientific conduct

In summary, Saudi Arabia chemistry-related industries are major contributors in the national economy and chemists of high-quality skills are required. Therefore, modern, and professional chemistry programs should meet this demand. Chemistry programs should also provide students with knowledge and experiences through which they can develop critical transferrable skills, listed above, to be competent to enter the workforce.

Appendix (E): Further Key Requirements for the Implementation of Chemistry Program Curriculum:

Although the National Centre for Academic Accreditation and Evaluation has developed several standards for program quality assurance, there is still a critical need to develop some specialized key requirements for chemistry programs in the Kingdom in order to guide universities to meet the required learning outcomes of the program. In this section, we introduce the key requirements for the chemistry program which are not explicitly covered in programs accreditation standards.

1. **Knowledge:**
   - 1.1 The program curriculum should cover a broad understanding of essential knowledge units and in-depth knowledge of the general key units described earlier.
   - 1.2 If the program provides track/tracks designed to cover emerging areas of chemistry or to meet local labor market needs in academia or industry, then tracks should not affect the core knowledge of foundation in chemistry in the program. However, the track should provide the threshold knowledge and laboratory skills for the track, the minimum contact hours for the track should not be less than 70% of total contact hours of the final year.

2. **Practical Skills:**
   - 2.1 As chemistry is an experimental science, therefore, the program must provide substantial laboratory-based contact hours and include, synthesis of molecules, properties measurements, structures determination, hands-on experience with modern instrumentation and data analysis and reporting.
   - 2.2 Laboratory experience in chemistry program must fall within the range of 40-50% of total contact hours of core chemistry courses in the program (exclusive of chemistry experience units)
   - 2.3 The Program must have modern, standard quality and continuously maintained instrumentations and specialized laboratory equipment, which should include:
     1. pH meters,
     2. conductivity meters,
     3. UV/Vis spectrophotometer,
     4. FTIR, Flame photometer
     5. ICP,
     6. HPLC-UV.
     7. GC-FID,
     8. Potentiometers with some ISEs, Electrophoresis,
     9. NMR spectroscopy.
   - 2.4 The Program must provide access to computing facilities, computational chemistry software, technical database, and chemical literature.
   - 2.5 The Program must have a well-established system for health and safety practice which must conform to national stated regulations for chemistry laboratories. This system should include:
     - Hazard identification database
     - Risk assessment procedures
     - Laboratory management system
     - Regular examination and inspection
     - Continuous awareness program
     - Waste management
     - Standard operating procedures
     - Sufficient personal protective equipment
     - Reporting and analysis of accidents
   - 2.6 For a safe and effective laboratory experience, number of students in the laboratory should not exceed 25 with an adequate number of instructors and assistants.

2.7 The Program should develop, review, approve and implement appropriate assessment methods with explicit RUBRICS to ensure all aspects of laboratory experience are fairy and rigorously assessed.

2.8 The Program must devote reasonable contact hours for students to develop their skills in problem-solving, critical thinking and analytical reasoning. This can be achieved in relevant courses via tutorials, small group discussions, and a student's forum.

3. Chemistry Experience Units

3.1 The program must provide a platform for students to experience different form of activities where they can independently integrate their knowledge and skills across chemistry disciplines. These activities can include:

1. Research project
2. Field experience
3. Extended case study
4. Literature investigation
5. Collaborative project
6. Voluntary Project
7. A year in industry

3.2 The chemistry experience activities should be conducted with at 180 contact hours during summer of the final year.

3.3 The research project should maintain high quality research so it instructs students to apply their understanding of all chemistry subdisciplines, laboratory skills, and instrumentation handling to solve complex problems and answer research questions. Reasonable time should be offered for a student to carry out literature studies, experimental investigation and produce a publishable well-written thesis.

3.4 The Program must maintain control and supervision of chemistry experience unit activities and field experience, according to NCAAA Field Experience Description.

3.5 Field experience assessment should be properly developed with explicit RUBRICS.

3.6 The Program must ensure that the nature and content of activities within chemistry experience units' activities are chemistry related.

3.7 The Program must ensure that experiences within chemistry experience units domain expose students to a wide range of transferrable skills which are required for professional chemists. These skills include:

- Communication skills
- Ethics
- Networking
- Information technology
- Teamwork skills
- Leadership & management
- Literature & information management