1. **Title of the module**
   Synthetic Chemistry Module 3 – GSKCHEM3

2. **School or partner institution which will be responsible for management of the module**
   GSK

3. **The level of the module (Level 4, Level 5, Level 6 or Level 7)**
   HE Level 4 / NQF Level 7

4. **The number of credits and the ECTS value which the module represents**
   15 credits

5. **Which term(s) the module is to be taught in (or other teaching pattern)**
   Spring

6. **Prerequisite and co-requisite modules**
   Pre-requisite: GSK/Chem 1 – Synthetic Chemistry Module 1

7. **The programmes of study to which the module contributes**
   This is a recommended module for the Postgraduate Certificate in Professional Development.

8. **The intended subject specific learning outcomes.**
   **On successfully completing the module students will be able to:**

   **Synthesis of Heterocycles**
   
   8.1 Recognises the key role of ammonia (amines) and carbonyl compounds in the formation of heterocycles and can identify the two key reaction types (imine formation and enamine aldol).
   8.2 Can identify 3 different synthetic strategies for the synthesis of pyridines (5C+1N), (2C+2C+1C+N) and (2C+2C+2C+N) and is able to exemplify 2 of these strategies.
   8.3 Is familiar with 2 synthetic strategies for quinolines and 2 for isoquinolines and can provide examples.
   8.4 Is aware of the common starting material which can provide pyrroles, thiophenes and furans and can exemplify all 3 reaction variants.
   8.5 Demonstrates awareness of the key role of dicarbonyl compounds in synthetic routes to diazines (pyrazines, pyridazines and pyrimidines) and can exemplify for 2 of these.
   8.6 Can provide an example of the synthesis of both 1,2-azoles and 1,3-azoles.
   8.7 Is familiar with the Fischer synthesis of indoles and can provide brief details of 2 other strategies for indole ring construction.

   **Catalytic Organometallic Chemistry: Beyond Palladium**
   
   8.8 Understands the key disadvantages associated with Pd catalysis (primarily cost, environmental impact) and the need to find alternatives.
   8.9 Can explain the significance of the 18-electron rule in the role of transition metals in organic synthesis, provide examples of 16-electron ‘exceptions’ and can demonstrate how to count the electrons in a complex.
   8.10 Recognise that iron is a cheap and environmentally benign catalyst.
   8.11 Can describe examples of reactions that iron can catalyse (cross-couplings, addition reaction, substitutions, cycloadditions etc.)
   8.12 Recognise that copper is a cheap alternative to palladium.
   8.13 Can describe examples of reactions that copper can catalyse (C-Het bond formation, C-C cross couplings etc.)
   8.14 Recognises metal catalysis is a rapidly developing area with new process being discovered almost daily.
   8.15 Shows an appreciation of ground-breaking advances in the field and new metals being used (e.g. Ir, Ru, Rh etc.).
8.16 Appreciates and can give examples of ‘state-of-the-art’ metal catalysed reactions (e.g. C-H activation leading to functionalisation – arylation, hydroacylation, borolation, atom insertions).

Reactive Intermediates

8.17 Can exemplify the generation and synthetic utility of dihalocarbenes in both ring expansion and ring formation reactions.
8.18 Is familiar with the general chemical structures / features of carbenes and nitrenes, including the alternative representations and the existence of singlet and triplet states. Can identify general reaction types for generation of both carbenes and nitrenes.
8.19 Recognises the key role played by bond insertion in the chemistry of carbenes and nitrenes and can provide examples of both intermolecular and intramolecular reactions (e.g Reimer Tieman reaction and 5-membered ring formation).
8.20 Can describe an example of both cyclopropanation and aziridination and is aware of the asymmetric variants of both reactions.
8.21 Demonstrates awareness of the role of metals in providing carbenoid (and more recently nitrenoid) species with moderated activity and hence increased selectivity. Is able to identify 2 transition metals which have been used.
8.22 Is aware of the utility of stable transition metal carbenoids in promoting metathesis reactions and can provide a general reaction mechanism for such reactions.
8.23 Is familiar with the basic processes which drive radical chemistry (atom abstraction, β-scission, rearrangement, radical-radical reactions and additions to π-bonds) and the key role which chain reactions play in radical processes.
8.24 Is aware of the existence of both ‘nucleophilic’ and ‘electrophilic’ radicals and can demonstrate how molecular orbital considerations can explain these reactivities.
8.25 Can exemplify the key role played by radical species in cyclisation reactions, including an example of a tandem radical cyclisation using either acyl or nitrogen centred radicals.
8.26 Recognises the utility of 1,5-hydrogen abstraction in the functionalisation of remote carbon atoms and can exemplify with either the Hofmann-Loffler-Freytag or Barton reactions.
8.27 Demonstrates awareness of the utility of radical reactions in achieving ring expansion and can show how this works for either 1-carbon or 3-carbon expansions.
8.28 Can describe a general example of a ring expansion reaction using an aminyl radical which provides a macrocyclic lactam.

Pericyclic Reactions

8.28 Shows and understanding of the molecular theory that underpins pericyclic reactions (e.g. FMO theory, Woodward-Hoffmann rules).
8.29 Demonstrates knowledge of the mechanistic nature of most cycloaddition reactions (concerted) and is aware of the 3 methods which can be used to predict thermal vs photochemical conditions and the expected regiocontrol and stereocontrol in cycloadditions.
8.30 Recognises that concerted cycloadditions involve suprafacial interactions of molecular orbitals and leads to conservation of stereochemistry whereas antarafacial molecular orbital interactions are characteristic of stepwise cycloadditions where steric interactions are often unfavourable and stereochemical information is lost.
8.31 Is able to identify the 5 principal types of cycloadditions (2+1, 2+2, 3+2, 4+2, 6+4) and can provide a general example of each type.
8.32 Can exemplify the processes involved in the formation of ketenes and their reaction with olefins to form cyclobutanones.
8.33 Is familiar with the formation and use of 1,3-dipoles in cycloadditions and can identify 3 types of 1,3-dipole (ozone, diazoalkanes, nitrones, nitrile oxides, azomethine ylides) and the products which result from their reactions with olefins.
8.34 Recognises the key role played by the Diels Alder reaction in organic synthesis. Is familiar with the ‘Kinetic Endo Effect’ and can use this to predict the stereochemistry of a typical DA cycloaddition. Can identify 2 ways of accelerating DA reactions (Lewis acid and pressure).

8.35 Recognises other electrocyclic and sigmatropic reactions.

8.36 Can explain the differences in structural outcome seen when conducting electrocyclic reactions under thermal or photochemical conditions (e.g. con- and dis-rotatory mechanisms).

Asymmetric Synthesis

8.37 Demonstrates awareness of the 3 ways in which asymmetric synthesis is commonly achieved – starting from the chiral pool, use of chiral auxiliaries and use of chiral reagents, including chiral catalysts.

8.38 Can identify common chiral pool molecule classes, including sugars, amino acids and terpenes.

8.39 Is familiar with the principles of the Chiron approach, including cases where existing asymmetry is preserved (correlation), partially destroyed, used to induce additional asymmetry in new stereochemical centres (communication).

8.40 Provides details of the concept of chiral auxiliaries and can identify the properties of a good chiral auxiliary including – cheap, easily available in both optically active forms, readily attached and removed from the substrate.

8.41 Can give examples of reaction types to which the use of chiral auxiliaries has been successfully applied, including 2 specific examples – e.g aldol, Diels-Alder, amino acid synthesis.

8.42 Demonstrates knowledge of the use of chiral reagents in asymmetric synthesis including boranes / boronates, chiral bases and application of tartrates in asymmetric epoxidation.

8.43 Is aware of developments in asymmetric catalysis and can identify 1 chemical and 1 enzymatic example.

Biological Chemistry

8.44 Can name the natural amino acids, recall their structures and abbreviations, and their role as the building blocks of proteins.

8.45 Show an understanding of protein structure and methods of synthesis (e.g. Strecker synthesis of AAs, Merrifield - peptides, 1º structure, B-sheets, disulfide bridges, helices etc.).

8.46 Know the structure of the nucleic acids and understand how they build up to form DNA.

8.47 Show an appreciation of the structural features of DNA (base pairing, double-helix).

8.48 Demonstrates a good understanding of the principal mechanisms in biochemical reactions and how they relate to laboratory techniques (e.g. NADPH – hydride reduction, pyridoxal phosphate – reductive amination, acetyl CoA – enol chemistry).

8.49 Understands and can work through some of the the key biosynthetic pathways (citric acid cycle, shikimic acid pathway, metabolism).

8.50 Be able to give examples of the complex natural products that come about via the aforementioned biosynthetic pathways (e.g. fatty acids, polyketides/lipids, prostaglandins, terpenoids, alkaloids, carbohydrates).

9. The intended generic learning outcomes.
On successfully completing the module students will be able to:

Heterocycle Assembly

9.1 Recognise the common reactions involved in heterocycle assembly, and the importance of carbonyl group chemistry to these (applying knowledge gained in Module 1) (A7, B1c, B1d, B1f, B1g, Cm, Cn, Co).

9.2 Appreciate the importance of oxidation/reduction steps in the syntheses of heterocyclic systems (A2, B1c, B1d, B1f, B1g, Cm, Cn, Co).
9.3 Demonstrate knowledge of several standard approaches to the synthesis of key nitrogen-containing heterocycles e.g pyridines, quinolines, pyrroles, and apply to the synthesis of selected target molecules, as appropriate (A1, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

Catalytic Organometallic Chemistry: Beyond Palladium

9.4 Demonstrate an understanding of the basic principles of organotransition metal chemistry (A7, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.5 Show a sound understanding of the mechanisms of commonly used coupling reactions involving catalysis by transition metals and their complexes above and beyond palladium based systems (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.6 Appreciate the breadth of reactions that organometallic chemistry offers the synthetic organic chemist, and recognise the continuous advances in this area (A2, A4, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.7 Identify the potential for the use of metal catalysed reactions in ongoing programmes of work, as appropriate (A1, A4, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

Reactive Intermediates

9.8 Explain the mechanisms of synthetic reactions involving particular “reactive intermediates” specifically, but not limited to, nitrenes and carbenes (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.9 Appreciate the synthetic utility of the reactions of these species, and apply to the synthesis of selected target molecules as appropriate (A1, A4, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.10 Demonstrate an understanding of the mechanisms of radical reactions used in modern synthesis, particularly within the context of intramolecular reactions (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.11 Appreciate the synthetic utility of radical reactions, and apply to the synthesis of selected target molecules as appropriate (A1, A4, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq, Cs, Ct).

Pericyclic Reactions

9.12 Understand the fundamental theory that underpins pericyclic reactions (FMO theory, Woodward-Hoffmann rules) (A2, A7, B1a, B1c, B1d, B1f, B1g).
9.13 Demonstrate an understanding of the key mechanisms underlying synthetically useful cycloaddition reactions (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.14 Also show an understanding of other sigmatropic and electrocyclic reactions, and their outcomes depending on whether under thermal or photochemical conditions (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Cq).
9.15 Apply the acquired knowledge to construct ring systems in a predictable regio- and stereo-controlled manner (B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).

Asymmetric Synthesis

9.16 Recognise, understand and apply the terms used in the description of asymmetric molecules (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.17 Understand the types of methods used in asymmetric synthesis, e.g. use of chiral auxillaries, chiral reagents and chiral catalysts, appreciating the synthetic opportunities provided by each method (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.18 Select appropriate reactions/methods to achieve the synthesis of selected targets, as appropriate (A1, A4, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

Biological Chemistry
9.19 Demonstrate a thorough knowledge of the key ‘building blocks of life’ (amino acids – proteins, nucleic acids – DNA) (A2, A7, B1a, B1c, B1d, B1f, Cm, Cn, Co, Cq).
9.20 Understand principal mechanisms in biological chemical reactions (A2, A7, B1a, B1c, B1d, B1f, Cm, Cn, Co, Cq).
9.21 Recognise key pathways and their role in the biosynthesis of complex natural products (A2, A7, B1a, B1c, B1d, B1f, Cm, Cn, Co, Cq).

10. **A synopsis of the curriculum**

The module provides a continuing framework of learning for new staff entering the company, primarily recent Chemistry graduates. However, it is also suitable for those who have more industrial experience, but who wish to refresh and build on their knowledge and appreciation of synthetic chemistry. This group may include staff who initially joined the company without a first degree, but who have achieved an equivalent qualification by part time study.

11. **Reading list (Indicative list, current at time of publication. Reading lists will be published annually)**

- Lecture notes and tutorial questions are normally made available in advance of each session. Further study of the subject is encouraged and this will improve the participant’s skills in efficient and effective literature retrieval and extraction of information.

**General**


**Heterocycle Assembly**


**Catalytic Organometallic Chemistry: Beyond Palladium**


**Reactive Intermediates**


**Pericyclic Reactions**


**Asymmetric Synthesis**

12. **Learning and teaching methods**

This module will be taught by using a lecture and tutorial format; the lectures will be delivered by external academics.

Independent learning hours will include literature searching, private study and assessment work

Total Learning hours: 150

13. **Assessment methods**

13.1 **Main assessment methods**

Successful completion of the module will require the participant to pass all aspects of the assessment process. These comprise completed tutorial problems, a written report and a *viva voce* examination.

The participant will be required to write a report of 2500 words maximum (minimum 2000 words), including chemical structures where appropriate. This report will exemplify how the material covered in at least two sessions from Module 3 have been (or may be) applied to an ongoing GSK research programme. Cross referencing to recently published literature and/or internal/external lectures would also be required.

The *viva voce* examination will be conducted by two selected senior/experienced members of staff, who are also likely to have an active involvement with our recruitment of PhD/Post-Doc qualified chemists, and thus a good appreciation of the level of knowledge and understanding we wish to assess. To initiate the detailed science-driven discussion, the participant will be asked to discuss a particular topic of their own choosing (using visual aids, as required). Through detailed scientific questioning, the assessor will seek to establish that the participant has appropriate knowledge and understanding at Masters level. The participant will be expected to defend their position during detailed chemistry questioning. Furthermore, the assessor will seek to establish understanding of a range of material covered in other sessions of Module 3. The focus will be on a high-quality issues-led discussion and debate, rather than a pre-set list of questions to be covered. This is an established practice at GSK.

The assessors will write a formal report, indicating whether the participant has successfully passed the module.

Clear guidelines and training where appropriate, will be provided to the assessors on how to conduct the *viva voce* examination, and the expected level of knowledge and understanding that the participant is required to demonstrate in order to pass the module. This will clearly be directly related to the Learning Outcomes described above.
The External Examiner will have access to:
- The participant’s worked solutions to tutorial questions
- The participant’s report
- The participant’s visual aids for viva voce examination
- Assessors’ report
- Any additional examples where the knowledge acquired has been applied in the workplace.

14. **Map of module learning outcomes (sections 8 & 9) to learning and teaching methods (section 12) and methods of assessment (section 13)**

<table>
<thead>
<tr>
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<th>8.1-8.50</th>
<th>9.1-9.21</th>
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<tbody>
<tr>
<td>Learning/teaching method</td>
<td>Hours allocated</td>
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<tr>
<td>Private Study</td>
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<td>X</td>
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<tr>
<td>Lectures</td>
<td>18</td>
<td>X</td>
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<tr>
<td>Tutorials</td>
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<td>X</td>
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<tr>
<td>Assessment method</td>
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<tr>
<td>Report</td>
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<tr>
<td>Solution to tutorial problems</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Viva voce</td>
<td>X</td>
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15. **Inclusive module design**

GSK recognises and has embedded the expectations of current equality legislation, by ensuring that the module is as accessible as possible by design. Additional alternative arrangements for students with Inclusive Learning Plans (ILPs)/declared disabilities will be made on an individual basis, in consultation with the relevant policies and support services.

The inclusive practices in the guidance (see Annex B Appendix A) have been considered in order to support all students in the following areas:

a) Accessible resources and curriculum
b) Learning, teaching and assessment methods

16. **Campus(es) or centre(s) where module will be delivered**

GSK Stevenage

17. **Internationalisation**

Chemistry is an international subject with new compounds, reaction pathways and techniques which are discovered, developed and refined by scientists across the globe. Mastery of the subject-specific learning outcomes will equip students to apply the theories and techniques of this module in a wide range of international contexts. GSK is large multi-national organisation which enables students to
appreciate the international aspects and benefits of scientific research and development. In compiling the reading list, consideration has been given to the range of materials that are available internationally and a selection of texts has been identified to complement the delivery of the material.

18. **Partner College/Validated Institution**
   GSK Stevenage

19. **University School responsible for the programme**
   Physical Sciences

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Revision record – all revisions must be recorded in the grid and full details of the change retained in the appropriate committee records.

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<tr>
<th>Date approved</th>
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<th>Start date of the delivery of revised version</th>
<th>Section revised</th>
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