1. **Title of the module**
   Synthetic Chemistry Module 1 – GSKCHEM1

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**
   10 credits

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

6. **Prerequisite and co-requisite modules**
   None

7. **The programmes of study to which the module contributes**
   This is a compulsory 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:

   **Carbonyl and Enolate Chemistry**
   8.1 Recognise the key role played by the carbonyl group as an electrophile in organic synthesis. Is aware of the various models proposed to explain the stereochemistry of addition to carbonyl groups – Cram, Felkin-Ahn, Cornforth.
   8.2 Identify the 3 ways in which enantioselective 1,2-addition to carbonyl groups can be achieved – chiral auxiliary, chiral reagent, chiral catalyst – and can exemplify.
   8.3 Demonstrate knowledge of enolate formation from a range of carbonyl compounds; is able to rationalise the relative ease of formation of such enolates (pKa of ketones, aldehydes, esters, acids, amides, malonate).
   8.4 Understand the importance of enolate geometry in determining the stereochemical outcome of reactions and is aware of how the choice of reagent and / or solvent can lead to selective trans or cis enolate formation – e.g. use of different boron enolates, addition of HMPA to lithium bases.

   **Oxidation and Reduction**
   8.5 Recognise and can exemplify the importance of oxidation for the introduction (and subsequent modification) of functionality in organic synthesis.
   8.6 Able to identify a number of both 1 and 2 electron oxidants and provide examples of their utility.
   8.7 Demonstrate knowledge of catalytic oxidation processes and can identify the advantages which such processes offer.
   8.8 Exemplify the utility of a number of reducing agents, including correctly identifying the ‘type’ – nucleophilic hydride, electrophilic, metal, non-metal.
   8.9 Recognise the key role played by asymmetric reduction reactions in organic synthesis and can exemplify with reagents based on aluminium, ruthenium and boron.

   **Reaction Selectivity: Protecting Group Chemistry**
   8.10 Understand the need for protecting groups in modern synthetic organic chemistry.
   8.11 Identify various strategies involved in selecting protecting groups (acid, base, hydrogen, palladium labile); recognises examples of incompatibility.
   8.12 Recognise which functional groups routinely require protection during complex multistep syntheses and can provide examples.
   8.13 Provide the properties of an ideal protecting group, including examples of where these requirements are met.
8.14 Describe and differentiate between uniform, orthogonal and graded deprotection strategies.
8.15 Identify opportunities for chemoselective synthesis without the need for protecting groups.

Retrosynthetic

8.16 Understand the value of retrosynthetic analysis in planning for success in complex, multistep organic synthesis.
8.17 Can demonstrate the principles of retrosynthetic analysis on a suitable example – identifying the key elements of carbon skeleton construction, introduction of functionality and the setting up of stereochemistry.
8.18 Explain ‘linear’ and ‘convergent’ synthesis and recognises the advantages of the latter.
8.19 Integrate knowledge of protecting group chemistry into retrosynthetic analysis.
8.20 Identify a range of group disconnections including ‘one group’ and ‘two group’ disconnections, the ‘umpolung’ concept and the value which radical disconnections bring to organic synthesis.

Catalytic Transition Metal Chemistry

8.21 Demonstrate an understanding of how the 2 common oxidation states of palladium provide access to a wide range of (often complementary) synthetic transformations. Is able to identify typical Pd(0) and Pd(II) catalysts.
8.22 Identify the organopalladium reaction mechanism types – ligand substitution, oxidative addition / reductive elimination, migratory insertion / β-hydride elimination, nucleophilic attack and transmetalation.
8.23 Recognise the different types of coupling reaction of Pd, Fe and Cu (Suzuki, Stille, Negishi, Sonagashira, Heck, Kumada, Buchwald-Hartwig, Ullmann, etc.); able to supply examples of substrates, catalysts and products.
8.24 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.
8.25 Show an understanding of the use of non-aryl-aryl cross coupling reactions for the modification of alkenes at the sp2 centre and can identify the commonly used variants - Suzuki, Stille, Heck.
8.26 Be familiar with the order of complexation of alkenes with Pd(II) in terms both of substitution and electron rich/poor and can identify and exemplify, in a general sense, reactions of Pd(II) alkene complexes with 3 types of nucleophiles (oxygen, nitrogen and carbon).
8.27 Identify Pd(0) catalysed insertion processes (CO, alkene) and exemplify one of these (carbonylation, Heck reaction).

Green Chemistry

8.28 Recognise the key role green chemistry has in protecting our environment (e.g. cost of waste – environmentally and monetarily, environmental disasters etc.).
8.29 Demonstrate an awareness of the key principles in green chemistry: waste prevention, maximising the incorporation of starting materials in chemical synthesis, generation of non-hazardous substances, chemical products designed so as to be non-toxic, use of catalysts, minimisation of energy demands in chemical syntheses, use of increasingly renewable raw materials etc.
8.30 Appreciate the key aims and order of preference when designing greener chemical processes (replacement of hazardous materials, reduction of chemical usage, recycling, benign disposal).
8.31 Demonstrate an understanding of new green technologies such as the use of enzymes, catalysis, flow chemistry, SC CO₂, aqueous systems.
8.32 Understand and can calculate fundamental green chemistry metrics (yield, effective mass yield [EMY], E Factor, Atom Economy [AE], Mass Intensity [MI], Carbon Efficiency [CE], Reaction Mass Efficiency [RME]) and appreciates their relative merits.
8.33 Is aware of renewable sources of chemicals.

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

**Carbonyl and Enolate Chemistry**

9.1 Demonstrate a thorough knowledge and understanding of the classical reactions of the carbonyl group and the enol/enolate functionality (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.2 Show an appreciation of the stereochemical consequences of reactions at a carbonyl centre, and the factors influencing these (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.3 Relate this material to other sessions in Module 1, particularly those covering Retrosynthesis and Oxidation/Reduction (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).

**Oxidation and Reduction**

9.4 Demonstrate a thorough knowledge and understanding of the classical and modern methods of metal and non-metal mediated oxidation reactions (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.5 Demonstrate a thorough knowledge and understanding of reduction chemistry (concentrating on reductions of carbonyl groups and carbon-carbon multiple bonds) (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.6 Identify and select appropriate oxidation or reduction methods to effect requisite synthetic chemistry transformations towards target molecules (A1, A4, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

**Reaction Selectivity: Protecting Groups**

9.7 Demonstrate knowledge and understanding of the properties and stabilities of commonly used protecting groups (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.8 Identify and select the most appropriate protecting group(s) to enable the completion of a given synthetic sequence (A4, B1a, B1c, B1d, B1f, B1g, Cn, Co).
9.9 Demonstrate an awareness of the use of protecting groups in recently published syntheses, including the development of novel protecting groups when required (A2, A4, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.10 Recognise the potential of novel or unusual protecting groups for in-house applications (A1, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

**Retrosynthesis**

9.11 Demonstrate confidence in the use of the techniques and terminology of retrosynthesis, e.g. disconnections, synths, umpolung (A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.12 Apply retrosynthetic analysis to deduce appropriate reagents for the synthesis of target molecules (A2, B1a, B1c, B1d, B1f, B1g, Cn, Co).
9.13 Critically assess the results of such an analysis, and propose, with reasoning, the preferred route of choice (A1, B1b, B1e, B1h, B2j, Cm, Cn, Co, Cq, Cs, Ct).

**Catalytic Transition Metal Chemistry**

9.14 Demonstrate a thorough understanding of the principles underlying catalytic organopalladium, copper and iron chemistry (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.15 Show a sound understanding of the mechanisms of commonly used palladium, copper and iron mediated coupling reactions (A2, A7, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).
9.16 Appreciate the breadth of reactions that organopalladium, copper and iron chemistry offers the synthetic organic chemist, and recognise the continuous advances in this area (A2, B1a, B1c, B1d, B1f, B1g, Cm, Cn, Co, Cq).

9.17 Identify the potential for the use of Pd, Cu and Fe catalysed reactions in ongoing programmes of work, as appropriate (A1, A4, B1b, B1e, B1h, B2j, Cn, Co, Cq, Cs, Ct).

9.18 Demonstrate an understanding of the basic principles of green chemistry (A2, A7, B1b, B1e, B1h, Cm, Cn, Co, Cq).

9.19 Show an understanding of the importance of being green in a chemical environment (A2, B1a, B1c, B1d, B1f).

9.20 Be able to identify examples of greener alternatives to well-known standard chemicals (reagents/solvents etc.) (A2, A4, B1b, B1e, B1h, B2j, Cm).

9.21 Identify the potential to use ‘greener’ processes in ongoing programmes where appropriate (A1, A4, B1b, B1h, B2j, Cn, Co, Cq, Cs, Ct).

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


Carbonyl and Enolate Chemistry

- http://www.organic-chemistry.org/namedreactions/
- http://www.name-reaction.com/
- http://chemistrybydesign.oia.arizona.edu/
- http://www.chem.wisc.edu/areas/reich/syntheses/syntheses.htm

Oxidation and Reduction

Module Specification

Reaction Selectivity: Protecting Groups

Retrosynthesis

Catalytic Organometallic Chemistry: Palladium

Green Chemistry

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: 100

13. Assessment methods
13.1 Main assessment methods
At the end of this module, 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 1 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 participant’s supervisor will provide written justification regarding their assessment of the final report. The supervisor’s line manager will review,

Clear guidelines and training where appropriate, will be provided to the both the supervisor and the supervisor’s line manager on how to assess the report. This will 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 supervisor’s and supervisor’s line manager’s assessment summaries
- 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>
<th>Module learning outcomes</th>
<th>8.1 – 8.33</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>
<td>76</td>
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<td>Lectures</td>
<td>12</td>
<td>X</td>
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<tr>
<td>Tutorials</td>
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<tr>
<td>Assessment method</td>
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<tr>
<td>Report</td>
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<tr>
<td>Solutions to tutorial problems</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 a 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
Revision record – all revisions must be recorded in the grid and full details of the change retained in the appropriate committee records.

<table>
<thead>
<tr>
<th>Date approved</th>
<th>Major/minor revision</th>
<th>Start date of the delivery of revised version</th>
<th>Section revised</th>
<th>Impacts PLOs (Q6&amp;7 cover sheet)</th>
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