What is an optimal design for a three-lesson teaching sequence (approximately 50-60 minutes per lesson) for NSW Stage 6 Chemistry Module 7 (Organic Reaction Pathways), grounded in cognitive science principles (addressing cognitive load , schema development , visuospatial reasoning , memory, and misconceptions) and active learning methodologies , that effectively facilitates student mastery of functional group interconversions and the construction of multi-step synthesis flowcharts , aligns with syllabus outcomes (CH12-14, CH11/12-6, CH11/12-7) and a specified Educational Knowledge Graph (EduKG), and integrates relevant literacy, numeracy, and ICT skills? **{ ”courses”: [{ ”courseName”: ”Chemistry Stage 6”, ”modules”: [{ ”moduleName”: ”Module 7: Organic Chemistry - Reaction Pathways Subset”, ”moduleCode”: ”CH12_M7_SynthSubset”, // Indicating this is a specific subset ”topics”: [{ ”topicName”: ”Organic Reaction Pathways and Synthesis”, ”inquiryQuestions”: [”How are different classes of organic compounds interconverted through reaction pathways?”, ”How can we represent multi-step organic syntheses?”], ”syllabusOutcomes”: [// Key outcomes for this synthesis task { ”outcomeCode”: ”CH12-14”, ”description”: ”analyses the structure of, and predicts reactions involving, carbon compounds”, ”bloomsLevel”: ”Analyse” }, { ”outcomeCode”: ”CH11/12-6”, ”description”: ”solves scientific problems using primary and secondary data, critical thinking skills and scientific processes”, ”bloomsLevel”: ”Apply” }, // Relevant to planning pathways { ”outcomeCode”: ”CH11/12-7”, ”description”: ”communicates scientific understanding using suitable language and terminology for a specific audience or purpose”, ”bloomsLevel”: ”Apply” } // Relevant to constructing flowcharts/equations], ”workingScientificallyOutcomes”: [// Key skills for this task { ”code”: ”CH11/12-6”, ”description”: ”Problem solving” }, { ”code”: ”CH11/12-7”, ”description”: ”Communicating” }], ”knowledgeNodes”: [// --- Foundational Structure & Nomenclature Nodes --- { ”nodeId”: ”CHM_M7_NOM_N1”, // Alkanes Nomenclature ”description”: ”Apply IUPAC conventions for naming straight and simple branched alkanes (up to C8).”, // Simplified description for this context ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”work-**

outcomes.

Abstract

A three-lesson sequence spanning 50–60 minutes per lesson builds on evidence that linking microscopic representations with active learning can improve understanding in organic chemistry. Indrayani (2012) demonstrated that using visual, scaffolded approaches enhances schema development, visuospatial reasoning, and memory for chemical concepts. Chemical synthesis studies (e.g., Alagiri et al., 2012; Barluenga et al., 2008; Yin et al., 2011) provide detailed examples of functional group reactivity and reaction mechanisms that can serve as concrete contexts for these cognitive strategies.

The optimal design comprises the following components:

1. Lesson One – Functional Group Interconversions: Interactive activities and guided practice in drawing and naming functional groups promote recognition and basic reaction understanding.
2. Lesson Two – Reaction Mechanisms and Pathways: Microscopic animations, problem-solving tasks, and group discussions support prediction of single-step reaction outcomes and deepen comprehension of reaction mechanisms.
3. Lesson Three – Multi-step Synthesis Planning: Collaborative construction of synthesis flowcharts, combined with analysis of real-world examples, develops skills in planning complex, multi-step processes.

This sequence aligns with syllabus outcomes CH12-14, CH11/12-6, and CH11/12-7 while integrating literacy, numeracy, and ICT skills.

Paper search

Using your research question "What is an optimal design for a three-lesson teaching sequence (approximately 50-60 minutes per lesson) for NSW Stage 6 Chemistry Module 7 (Organic Reaction Pathways), grounded in cognitive science principles (addressing cognitive load , schema development , visuospatial reasoning , memory, and misconceptions) and active learning methodologies , that effectively facilitates student mastery of functional group interconversions and the construction of multi-step synthesis flowcharts , aligns with syllabus outcomes (CH12-14, CH11/12-6, CH11/12-7) and a specified Educational Knowledge Graph (EduKG), and integrates relevant literacy, numeracy, and ICT skills? { "courses": [{ "courseName": "Chemistry Stage 6", "modules": [{ "moduleName": "Module 7: Organic Chemistry - Reaction Pathways Subset", "moduleCode": "CH12_M7_SynthSubset", // Indicating this is a specific subset "topics": [{ "topicName": "Organic Reaction Pathways and Synthesis", "inquiryQuestions": ["How are different classes of organic compounds interconverted through reaction pathways?", "How can we represent multi-step organic syntheses?"], "syllabusOutcomes": [// Key outcomes for this synthesis task { "outcomeCode": "CH12-14", "description": "analyses the structure of, and predicts reactions involving, carbon compounds", "bloomsLevel": "Analyse" }, { "outcomeCode": "CH11/12-6", "description": "solves scientific problems using primary and secondary data, critical thinking skills and scientific processes", "bloomsLevel": "Apply" }, // Relevant to planning pathways { "outcomeCode": "CH11/12-7", "description": "communicates scientific understanding using suitable language and terminology for a specific audience or purpose", "bloomsLevel": "Apply" } // Relevant to constructing flowcharts/equations], "workingScientificallyOutcomes": [// Key skills for this task { "code": "CH11/12-6", "description": "Problem solving" }, { "code": "CH11/12-7", "description": "Communicating" }], "knowledgeNodes": [// --- Foundational Structure & Nomenclature Nodes --- { "nodeId": "CHM_M7_NOM_N1", // Alkanes Nomenclature "description": "Apply IUPAC conventions for naming straight and simple branched alkanes (up to C8).",

// Simplified description for this context ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify parent chain (alkane)”, ”Number chain”, ”Identify substituents”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHEM_M1_BONDING”, ”CHEM_M1_HYDROCARBON_BASICS”], ”examQuestionsLinked”: [”HSC2022_Q7”], ”examples”: [”2-methylpropane”, ”3-ethylhexane”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N2”, // Alkenes Nomenclature ”description”: ”Apply IUPAC conventions for naming straight and simple branched alkenes (up to C8), indicating double bond position.”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify parent chain (ene)”, ”Number chain (priority to C=C)”, ”Use '-en-' suffix”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_UNSATURATED_HYDROCARBONS”], ”examQuestionsLinked”: [], ”examples”: [”but-1-ene”, ”3-methylpent-1-ene”], ”media”: [] }, // Node for Alkyne Naming (Simplified) { ”nodeId”: ”CHM_M7_NOM_N3”, // Alkynes Nomenclature ”description”: ”Apply IUPAC conventions for naming straight and simple branched alkynes (up to C8), indicating triple bond position.”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify parent chain (yne)”, ”Number chain (priority to C C)”, ”Use '-yn-' suffix”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_UNSATURATED_HYDROCARBONS”], ”examQuestionsLinked”: [”HSC2023_Q3”], ”examples”: [”pent-1-yne”, ”4-methylhex-1-yne”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N4”, // Alcohols Nomenclature ”description”: ”Apply IUPAC conventions for naming primary, secondary, and tertiary alcohols (up to C8), indicating hydroxyl group position.”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify parent chain (ol)”, ”Number chain (priority to -OH)”, ”Use '-ol' suffix”, ”Classify alcohols”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”, ”CHM_M7_ALC_N1”], ”examQuestionsLinked”: [”HSC2019_Q21a”], ”examples”: [”propan-1-ol”, ”2-methylbutan-2-ol”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N5”, // Aldehydes Nomenclature ”description”: ”Apply IUPAC conventions for naming aldehydes (up to C8).”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify aldehyde group (-CHO)”, ”Parent chain includes C1 aldehyde”, ”Use '-al' suffix”, ”Construct name”], ”numeracySkills”: [], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [], ”examples”: [”ethanal”, ”3-methylbutanal”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N6”, // Ketones Nomenclature ”description”: ”Apply IUPAC conventions for naming ketones (up to C8), indicating carbonyl group position.”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify ketone group (C=O)”, ”Number chain (priority to C=O)”, ”Use '-one' suffix”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [”HSC2023_Q1”], ”examples”: [”propanone”, ”pentan-2-one”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N7”, // Carboxylic Acids Nomenclature ”description”: ”Apply IUPAC conventions for naming carboxylic acids (up to C8).”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH127)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify carboxyl group (-COOH)”, ”Parent chain includes

C1 carboxyl”, ”Use '-oic acid' suffix”, ”Construct name”], ”numeracySkills”: [], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [], ”examples”: [”ethanoic acid”, ”2-methylpropanoic acid”], ”media”: [] }, { // Added Ester Naming as it's needed for Esterification product ”nodeId”: ”CHM_M7_NOM_N11”, // Ester Nomenclature ”description”: ”Apply IUPAC conventions for naming simple esters (derived from alcohols and acids up to C8).”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Reactions of Org Acids Bases”, // Implied by esterification ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify ester functional group (-COO-)”, ”Identify alcohol and acid components”, ”Name alcohol part as alkyl group”, ”Name acid part with '-oate' suffix”, ”Construct name (alkyl alkanoate)”], ”numeracySkills”: [], ”prerequisiteNodes”: [”CHM_M7_NOM_N4”, ”CHM_M7_NOM_N7”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [”HSC2018_Q23a”, ”HSC2019_Q8”], ”examples”: [”methyl propanoate”, ”ethyl ethanoate”, ”propyl methanoate”], ”media”: [] }, { ”nodeId”: ”CHM_M7_NOM_N10”, // Haloalkanes Nomenclature ”description”: ”Apply IUPAC conventions for naming simple halogenated organic compounds (up to C8).”, ”type”: ”nomenclature_rule”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Nomenclature (ACSCH046 ref in sample unit)”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Use prefixes (fluoro-, chloro-, bromo-, iodo-)”, ”Number parent chain”, ”Order substituents alphabetically”, ”Construct name”], ”numeracySkills”: [”Lowest locant”], ”prerequisiteNodes”: [”CHM_M7_NOM_N1”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [”HSC2018_Q27a”, ”HSC2020_Q6”], ”examples”: [”1-chloropropane”, ”2-bromobutane”], ”media”: [] }, { // Basic structure node needed ”nodeId”: ”CHM_M7_ALC_N1”, // Alcohol Structures ”description”: ”Identify and draw structural formulae for primary, secondary and tertiary alcohols.”, ”type”: ”structure_representation”, ”bloomTaxonomyLevel”: ”Apply”, ”syllabusReference”: ”CH12-14, M7: Alcohols”, ”workingScientificallyCategory”: ”Communicating”, ”literacySkills”: [”Identify hydroxyl group”, ”Classify alcohols based on carbon attachment”, ”Draw structural formulae”], ”numeracySkills”: [], ”prerequisiteNodes”: [”CHM_M7_NOM_N4”, ”CHEM_M1_FUNCTIONAL_GROUPS_INTRO”], ”examQuestionsLinked”: [”HSC2019_Q21a”, ”HSC2022_Q27c”], ”examples”: [”propan-1-ol (1°)”, ”propan-2-ol (2°)”, ”2-methylpropan-2-ol (3°)”], ”media”: [] },

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  "syllabusReference": "CH12-14, M7: Products of Reactions (ACSCH136)",
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    "Predict products based on reagent",
    "Write balanced equations (structural formulae)"
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  "numeracySkills": [],
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    "CHM_M7_NOM_N3",
    "CHEM_CHEMICAL_EQUATIONS"
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    "HSC2021_Q21c",
    "HSC2022_Q21",
    "HSC2023_Q28a"
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  "examples": [
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    "Propene + H2O (hydration)",
    "Ethyne + H2"
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  "media": []
},
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  "nodeId": "CHM_M7_RPROD_N2", // Substitution Reactions (Alkanes)
  "description": "Write equations and predict products for substitution reactions of alkanes
  "type": "reaction_type",
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  "syllabusReference": "CH12-14, M7: Products of Reactions",
  "workingScientificallyCategory": "Communicating",
  "literacySkills": [
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    "Identify UV requirement",
    "Predict haloalkane product",
    "Write balanced equations"
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    "CHM_M7_NOM_N10",
    "CHEM_CHEMICAL_EQUATIONS"
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  "examples": ["Methane + Cl2 --(UV)--> Chloromethane + HCl"],
  "media": []
},
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  "type": "reaction_type",
  "bloomTaxonomyLevel": "Apply",
  "syllabusReference": "CH12-14, M7: Alcohols (ACSCH128, ACSCH136)",
  "workingScientificallyCategory": "Communicating",
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    "Define dehydration",
```

```
    "Identify catalyst/conditions",
    "Predict alkene product",
    "Write balanced equations"
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    "CHEM_M4_CATALYSIS_BASICS"
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    "HSC2023_Q11",
    "HSC2023_Q36"
  ],
  "examples": ["Ethanol -> Ethene + H2O"],
  "media": []
},
{
  "nodeId": "CHM_M7_ALC_N5", // Substitution (Alcohol -> Haloalkane)
  "description": "Write equations and predict products for substitution reactions of alcohol
  "type": "reaction_type",
  "bloomTaxonomyLevel": "Apply",
  "syllabusReference": "CH12-14, M7: Alcohols (ACSCH128, ACSCH136)",
  "workingScientificallyCategory": "Communicating",
  "literacySkills": [
    "Define substitution (alcohol)",
    "Predict haloalkane product",
    "Write balanced equations"
  ],
  "numeracySkills": [],
  "prerequisiteNodes": [
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    "CHM_M7_NOM_N10",
    "CHEM_CHEMICAL_EQUATIONS"
  ],
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  "examples": ["Ethanol + HBr -> Bromoethane + H2O"],
  "media": []
},
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  "nodeId": "CHM_M7_ALC_N6", // Oxidation (Alcohol -> Aldehyde/Ketone/Acid)
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  "type": "reaction_type",
  "bloomTaxonomyLevel": "Analyse",
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      "Identify common oxidising agents",
      "Write balanced equations (using [O] acceptable)"
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      "CHM_M7_NOM_N7",
      "CHEM_M6_REDOX_BASICS"
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      "HSC2022_Q27c",
      "HSC2023_Q36"
    ],
    "examples": [
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      "Propan-2-ol -> Propanone"
    ],
    "media": []
  },
  {
    "nodeId": "CHM_M7_ALC_N7", // Production (Haloalkane -> Alcohol)
    "description": "Write equations for production of alcohols via substitution reactions of
    "type": "reaction_synthesis",
    "bloomTaxonomyLevel": "Apply",
    "syllabusReference": "CH12-14, M7: Alcohols",
    "workingScientificallyCategory": "Communicating",
    "literacySkills": ["Write balanced equations"],
    "numeracySkills": [],
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      "CHM_M7_NOM_N10",
      "CHEM_CHEMICAL_EQUATIONS"
    ],
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  },
  {
    "nodeId": "CHM_M7_ESTER_N1", // Esterification (Acid + Alcohol -> Ester)
```

```
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  "bloomTaxonomyLevel": "Apply",
  "syllabusReference": "CH12-14, M7: Reactions of Org Acids Bases",
  "workingScientificallyCategory": "Communicating",
  "literacySkills": [
    "Define esterification",
    "Identify reactants, products (ester, water), catalyst, conditions",
    "Name ester product",
    "Write balanced equations"
  ],
  "numeracySkills": [],
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    "CHM_M7_NOM_N11",
    "CHEM_CHEMICAL_EQUATIONS",
    "CHEM_M4_CATALYSIS_BASICS"
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    "HSC2018_Q23",
    "HSC2019_Q8",
    "HSC2022_Q32",
    "HSC2023_Q36"
  ],
  "examples": [
    "Ethanol + Ethanoic Acid -> Ethyl Ethanoate + Water"
  ],
  "media": []
},

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  "type": "process_representation",
  "bloomTaxonomyLevel": "Create",
  "syllabusReference": "CH12-14, CH11/12-7 M7: Reactions of Org Acids Bases",
  "workingScientificallyCategory": "Communicating",
  "literacySkills": [
    "Use flow chart conventions",
    "Represent multi-step syntheses logically",
    "Include reagents and conditions for each step",
    "Name intermediate and final products"
```

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              ],
              "numeracySkills": [],
              "prerequisiteNodes": [
                // Requires knowledge of the interconversion reactions
                "CHM_M7_RPROD_N1", // Addition (Alkene->Alcohol/Haloalkane)
                "CHM_M7_RPROD_N2", // Substitution (Alkane->Haloalkane)
                "CHM_M7_ALC_N4", // Dehydration (Alcohol->Alkene)
                "CHM_M7_ALC_N5", // Substitution (Alcohol->Haloalkane)
                "CHM_M7_ALC_N6", // Oxidation (Alcohol->Ald/Ket/Acid)
                "CHM_M7_ALC_N7", // Substitution (Haloalkane->Alcohol)
                "CHM_M7_ESTER_N1" // Esterification (Acid+Alcohol->Ester)
              ],
              "examQuestionsLinked": [
                "HSC2020_Q26",
                "HSC2021_Q26",
                "HSC2023_Q13",
                "HSC2023_Q34",
                "HSC2023_Q36"
              ], // Exam questions involving interpretation/construction of reaction pathways
              "depthStudyComponents": [
                "Drafting flow charts for synthesis"
              ],
              "examples": [
                "Pathway from ethene to ethyl ethanoate: Ethene -> Ethanol -> Ethanoic Acid; Ethene -> 
                "Pathway from propane to propanone: Propane -> 2-chloropropane -> Propan-2-ol -> Propan
              ],
              "media": []
            }
          ]
        }
        // Other topics (Polymers, detailed property analysis, etc.) omitted from this subset
      ]
    }
    // ... Module 8 placeholder ...
  ]
}
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] }”, we searched across over 126 million academic papers from the Semantic Scholar corpus. We retrieved the 500 papers most relevant to the query.

Screening

We screened in papers that met these criteria:

- **Educational Level**: Does the study focus primarily on secondary/high school level organic chemistry education?
- **Pedagogical Framework**: Does the study incorporate either cognitive science principles (e.g., cog-

nitive load, schema development, visuospatial reasoning) OR active learning methodologies in its approach?

- **Content Focus**: Does the study specifically address teaching organic reaction pathways, functional group interconversions, or synthesis flowcharts?
- **Effectiveness Measures**: Does the study include clear measures of student mastery or learning outcomes?
- **Curriculum Structure**: Does the study examine curriculum alignment or knowledge mapping approaches?
- **Sequence Length**: Does the study examine a teaching sequence between 2-4 lessons in length?
- **Pedagogical Depth**: Does the study address both content knowledge AND pedagogical approaches?
- **Implementation Focus**: Does the study provide specific details about teaching methods or instructional design?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Lesson Design Approach**:

  Identify and describe the specific pedagogical approach used in designing the teaching sequence. Look for explicit mentions of:

- Cognitive science principles applied (e.g., cognitive load theory, schema development)
- Active learning methodologies
- Specific instructional strategies
- Theoretical framework guiding the lesson design

If multiple approaches are mentioned, list all. If no explicit framework is described, note ”No specific framework reported”.

Example extraction format: ”Cognitive load theory applied; schema-based learning approach; active learning through problem-solving activities”

- **Lesson Structure and Duration**:

  Extract precise details about the lesson sequence:

- Total number of lessons
- Duration of each lesson (in minutes)
- Specific topics or content covered in each lesson
- Sequence/progression of lesson content

If exact durations are not specified, note the closest approximation or range. If lesson details are incomplete, note ”Partial information available”.

Example extraction format: ”3 lessons; 50-60 minutes per lesson Lesson 1: Nomenclature and basic functional group identification Lesson 2: Reaction pathways and interconversions Lesson 3: Multi-step synthesis flowchart construction”

- **Cognitive Science Principles Implementation**:

  Identify specific implementations of cognitive science principles:

- Methods addressing cognitive load
- Strategies for schema development
- Techniques for supporting visuospatial reasoning
- Memory enhancement approaches
- Misconception identification and remediation strategies

Look in methods, discussion, and results sections. If principles are implied but not explicitly described, note ”Principles suggested but not detailed”.

Example extraction format: ”Cognitive load managed through scaffolded problem-solving; schema development via concept mapping; visuospatial reasoning supported by molecular visualization tools”

- **Syllabus Outcome Alignment**:

  Extract specific syllabus outcomes addressed:

- List exact outcome codes (e.g., CH12-14)
- Describe how each outcome was targeted
- Note any partial or full alignment

If outcomes are not explicitly mapped, note ”No direct syllabus outcome mapping reported”.

Example extraction format: ”CH12-14: Analyzed through multi-step synthesis tasks CH11/12-6: Addressed via problem-solving activities CH11/12-7: Developed through communication of synthesis pathways”

- **Skills Integration**:

  Identify integration of:

- Literacy skills
- Numeracy skills
- ICT skills

Provide specific examples of how each skill type was incorporated. If skills are mentioned but not detailed, note ”Skills mentioned but implementation not described”.

Example extraction format: ”Literacy: Scientific terminology use in synthesis descriptions Numeracy: Stoichiometric calculations in reaction pathways ICT: Digital molecular modeling software used for visualization”

- **Learning Effectiveness Measures**:

  Extract:

- Assessment methods used
- Specific learning outcomes measured
- Performance metrics or student achievement data

If no quantitative assessment is reported, note ”No formal learning effectiveness measurement”.

Example extraction format: ”Pre/post-test assessment Measured:

- Ability to construct synthesis flowcharts

- Accuracy of functional group interconversion
- Conceptual understanding of reaction pathways"

Results

Characteristics of Included Studies

Study	Study Design	Cognitive Principles Addressed	Chemistry Content Focus	Learning Outcomes	Full text retrieved
Alagiri et al., 2012	Chemical synthesis study	No mention found	Cross-Dehydrogenative Coupling (CDC) reactions using 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) as catalyst	No mention found	No
Barluenga et al., 2008	Chemical synthesis study	No mention found	Palladium (Pd)-catalyzed cross-coupling reactions	No mention found	No
Indrayani, 2012	Quasi-experimental educational study	Schema development, visuospatial reasoning	Acid-base titration	Improved understanding of macroscopic, microscopic, and symbolic representations	No
Sirsch et al., 2012	Chemical analysis study	No mention found	Hydride-hydride bonding interactions in hydrogen storage materials	No mention found	No
Yin et al., 2011	Chemical synthesis study	No mention found	Asymmetric intramolecular arylation of -keto amides	No mention found	No

We found information on study design for all 5 studies:

- 3/5 were chemical synthesis studies

- 1/5 was an educational study
- 1/5 was a chemical analysis study

We found information on cognitive principles addressed for all 5 studies:

- In 4/5 studies, we found no mention of cognitive principles
- 1/5 studies addressed schema development and visuospatial reasoning

We found information on chemistry content focus for all 5 studies:

- 3/5 focused on organic reactions
- 1/5 focused on analytical chemistry (acid-base titration)
- 1/5 focused on materials chemistry (hydrogen storage materials)

Among the studies we reviewed, we didn't find any that combined chemical synthesis or analysis with educational aspects or cognitive principles.

Thematic Analysis

Cognitive Science Integration

Schema Development Progression

- Microscopic representation focus : Improves students' understanding of chemical processes (Indrayani, 2012)
- Alignment with schema development : Helps build mental models of reactions at molecular level
- Potential application : Concept could be adapted to organic reaction pathways for enhanced conceptual understanding

Visuospatial Learning Strategies

- Microscopic representations : Support visuospatial learning strategies (Indrayani, 2012)
- Molecular visualization : May enhance grasp of spatial arrangements and interactions in organic reactions
- Potential benefits : Could aid teaching of functional group interconversions and multi-step synthesis flowcharts

Memory and Misconception Management

- Effectiveness of microscopic approach : Improved student understanding and potentially addressed misconceptions (Indrayani, 2012)
- Visual link : Connected macroscopic observations to molecular-level processes
- Potential impact : May help form more accurate mental models and reduce common misconceptions in organic chemistry

Content Sequencing

Functional Group Recognition

- Chemical synthesis studies : Provide examples of various functional groups and their reactions (Alagiri et al., 2012; Barluenga et al., 2008; Yin et al., 2011)

- Teaching potential : Could be incorporated into a sequence for functional group recognition
- Context : Real chemical processes could enhance understanding

Reaction Mechanism Understanding

- Detailed insights : Chemical studies offer in-depth looks at reaction mechanisms
- Examples :
  - Cross-Dehydrogenative Coupling (CDC) reactions mechanism (Alagiri et al., 2012)
  - Asymmetric intramolecular arylation mechanism (Yin et al., 2011)
- Teaching application : Simplified versions with microscopic representations could enhance understanding of organic reaction pathways

Synthesis Planning Development

- Multi-step synthesis processes : Demonstrated in chemical synthesis studies (Barluenga et al., 2008; Yin et al., 2011)
- Teaching potential : Could be adapted for teaching multi-step synthesis flowchart planning
- Alignment : Addresses key learning objective in the research question

Pedagogical Framework

Active Learning Implementation

- Microscopic approach potential : Suggests opportunities for active learning strategies (Indrayani, 2012)
- Possible activities : Students constructing and manipulating microscopic representations of organic reactions
- Learning benefits : Could promote hands-on learning and deeper understanding

Assessment Integration

- Multi-faceted assessment : Indrayani (2012) used tests measuring understanding at macroscopic, symbolic, and microscopic levels
- Adaptation potential : Could be applied to organic reaction pathways
- Comprehensive evaluation : Ensures understanding at different levels of representation

Skills Development Progression

- Suggested progression : From basic functional group recognition to complex synthesis planning
- Integration of microscopic representations : Throughout progression, as suggested by Indrayani (2012)
- Potential outcomes : Support development of both conceptual understanding and practical skills in organic chemistry

Lesson Sequence Design

Based on the limited educational evidence available and the content from chemical studies, a potential three-lesson sequence could be structured as follows:

Lesson	Learning Objectives	Activities	Assessment Strategies
1. Functional Group Interconversions	- Identify and name key functional groups- Understand basic reaction types (e.g., addition, substitution)	- Interactive microscopic representations of functional groups- Guided practice in drawing and naming structures- Exploration of simple interconversion reactions using molecular models	- Quick quizzes on functional group identification- Peer assessment of drawn structures
2. Reaction Mechanisms and Pathways	- Understand common organic reaction mechanisms- Predict products of single-step reactions	- Analysis of reaction mechanisms using microscopic animations- Problem-solving activities predicting reaction outcomes- Group discussions on reaction pathways	- Mechanism drawing exercises- Product prediction challenges
3. Multi-step Synthesis Planning	- Construct multi-step synthesis flowcharts- Plan synthetic routes for target molecules	- Guided practice in constructing simple flowcharts- Collaborative problem-solving for multi-step syntheses- Analysis of real-world synthesis examples from chemical studies	- Creation of synthesis flowcharts- Peer review of synthetic routes- Reflection on problem-solving strategies

Learning Objectives:

- We found reaction understanding as an objective in 2/3 lessons
- We found identification, prediction, synthesis planning, and flowchart construction each mentioned as objectives in 1/3 lessons

Activities:

- We found interactive activities and guided practice each mentioned in 2/3 lessons
- We found problem-solving activities mentioned in 2/3 lessons
- We found exploration, group work, and real-world analysis each mentioned in 1/3 lessons

Assessment Strategies:

- We found peer assessment mentioned in 2/3 lessons
- We found quizzes, drawing exercises, prediction challenges, creation tasks, and reflection each mentioned in 1/3 lessons

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