A framework for interdisciplinary learning in science education

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Abstract Interdisciplinary learning (IDL) is an engaging approach that is growing in popularity in higher education but is still in its infancy in 11–18 science education. Herein we provide a framework that demonstrates the key components of high-quality IDL experiences as guidance for teachers. The framework explains the rigour of the interdisciplinary approach to learning and provides the IDL mechanism that develops problem-solving and metacognitive skills. Following a review of curriculum frameworks and guidance, we propose that IDL is an important pedagogical tool to help realise a future vision of science education.

There is a recognition among stakeholders in science education of the importance of engagement in supporting student learning and that this can be increased by making learning relevant to students by providing real-world examples (Harlen, 2010; Quigley and Coleman, 2018). Consider, though, that the challenges facing scientists today in the real world are highly complex. Research breakthroughs and problem-solving regularly require collaborative working and input from experts across multiple disciplines. Interdisciplinary working has become a natural product of humankind's curiosity and drive to solve global problems. It is therefore no surprise that interdisciplinary learning (IDL) is becoming a popular approach in some areas of education.

Interdisciplinarity is growing in popularity at universities, and many examples of its application are limited to higher education. Interdisciplinarity has such a diversity of applications that the internet and literature are flooded with definitions and examples that are not always relevant or accessible to a school classroom teacher. It is therefore very difficult to narrow down and characterise IDL for its use in the classroom and there is a need for more clarity and instruction for teachers.

In this article we propose a framework for IDL to be used in secondary school science teaching (ages 11–18). We also use this framework to interrogate future curriculum recommendations to assess the potential opportunities to incorporate IDL into everyday teaching through use of appropriate pedagogies.

Clarification of definitions

In interdisciplinary learning students integrate knowledge, concepts and practices from two or more disciplines in a way that generates an understanding of a topic or problem that goes beyond that of any single discipline (Boix Mansilla, 2016). Students make meaningful connections between disciplines that lead to a deeper assimilation of concepts (Ivanitskaya *et al.*, 2002). In many ways IDL embodies the philosophical phrase 'the whole is greater than the sum of its parts'.

It is the *integration* of multiple perspectives and knowledge across disciplines that identifies the difference between learning that is interdisciplinary and learning that is cross-disciplinary, where information across disciplines is more simply juxtaposed. *Synthesis* is used to describe creation of new understandings, ways of thinking and novel outcomes. It is a product of the combined processes involved in the interdisciplinary learning.

When considering the underlying processes involved in IDL as a whole, the term synthesis becomes useful. Synthesis is a well-defined term in education largely due to its use in Bloom's Taxonomy (Bloom, 1956). As a thinking skill, synthesis involves creating something new where learners might demonstrate skills such as innovation, adaptation, modelling, design, formulation and imagination, and as such IDL promotes these learning opportunities (Figure 1).

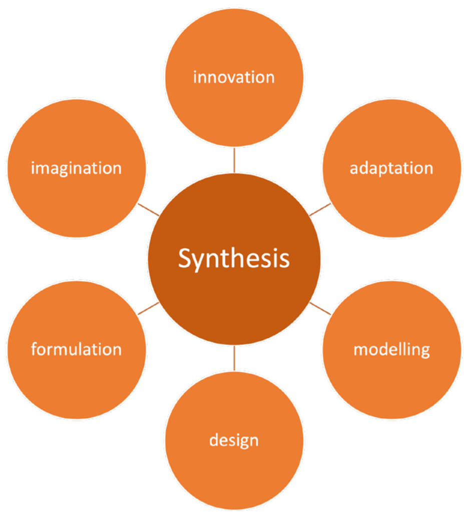

Figure 1 Skills and ways of thinking linked to synthesis

A framework for interdisciplinary learning

Here we propose a framework for using IDL in secondary school classrooms to provide clarity on what it is, and consistency in the rigour of how it is implemented. This is created for classroom teachers, senior leaders and policymakers in 11–18 education. While this framework can be adapted for use in any area of different curricula, we have created it from the viewpoint of teaching science in the English education setting. The framework, which contains three parts, encapsulates the processes used for interdisciplinary synthesis:

- purpose and task;
- disciplinary knowledge and understanding;
- integration.

This has been modified and adapted from the work by Boix Mansilla (2005; 2016) and Bammer (2013). A graphic representation of how these framework components interact is provided in Figure 2, and more detailed explanations follow.

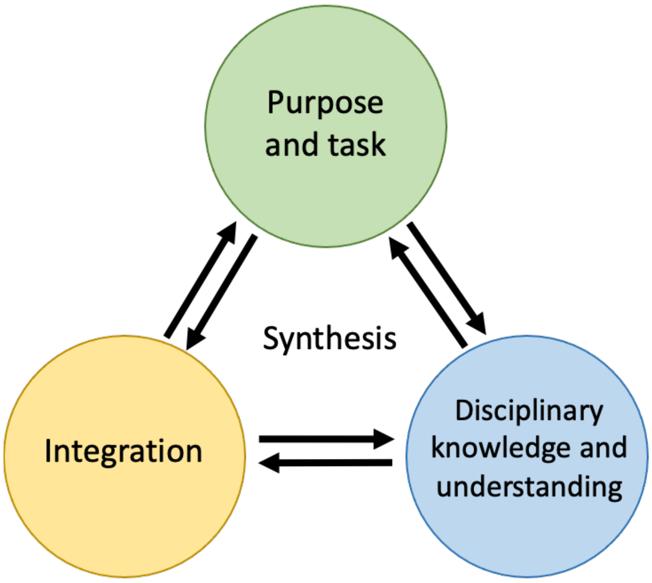

Figure 2 Graphic illustration of a framework and mechanism for interdisciplinary learning

Purpose and task

Real-world interdisciplinary working is driven by a purpose. In an educational setting we can borrow real-world examples to recreate that sense of purpose. Purpose might take the form of a guiding question or a statement of fact that reflects a *problem* or *vision* – the purpose behind creating the Statue of Liberty is an example of a real-world vision, whereas insufficient water supply during periods of drought is an example of a real-world problem.

In the classroom, the teacher sets a task that guides the student to explore the problem or vision. The task outlines to students the end product from the IDL, such as writing a report or delivering a presentation. By definition, IDL is open-ended, where there is not necessarily a single correct outcome or answer, and therefore this should be reflected in the nature of the chosen task and outcome. The suggestion here is one of goal-based synthesis, where the focus on solving a problem or achieving a vision facilitates interdisciplinarity (Bammer, 2013).

Revisiting our example of the Statue of Liberty can illustrate the clear difference and interdependence of the *purpose* and *task*: it was created for the purpose of expressing the values of liberty and democracy in America and the task was to create a lasting visual representation that achieves the purpose. Table 1 provides two examples of a purpose and task within the context of a science lesson.

Disciplinary knowledge and understanding

In IDL, students are required to already have, or to be provided with, relevant disciplinary knowledge and understanding. This gives the teacher the opportunity to identify two or more relevant disciplines and scaffold this acquisition or retrieval of knowledge. Two

Table 1 Illustrations of where interdisciplinary learning could be used in the classroom

Topic	Sustainability	Scientific concepts
Purpose	Problem: making your local city more sustainable	Vision: how do we think about science?
Task	Write a report outlining recommendations within a set budget	Write a poem using metaphor to explain the concept. This example could be applicable to any concept in science, e.g. intermolecular forces vs bond breaking, electricity, evolution, etc.
Disciplinary knowledge	• Chemistry: sustainability, pollutants • Geography: sustainable cities • Politics: local governance and budgeting	• Science: any given concept • English: metaphor, analogy, poetry structure and analysis
Integration	Teacher-led discussion exploring an authentic text might be used as an activity to facilitate the integration of disciplinary knowledge	Pair work and/or group work could be used to facilitate the sharing of ideas and to encourage metacognitive talk between students, refining and reshaping understanding

such examples are given in Table 1. It is important here for the teacher to upskill and/or collaborate with other subject specialists to build an understanding of students' prior knowledge and skills in these areas. During an IDL activity or lesson, students should be able to access an appropriate level of knowledge and understanding across the chosen topic areas, which enables them to interact successfully with the open-ended nature of the task – for example, by being provided with appropriate resources and stimulus material.

In our example of the Statue of Liberty, chemistry (properties of metals and corrosion), art (symbolism and visual impact), and history (American and French) are examples of the many relevant disciplines involved in its creation.

Integration

In real-world complex problem-solving, integration is achieved through collaboration of experts across different disciplines, bringing together multiple perspectives. For example, many teams of experts would have been involved in creating the Statue of Liberty. Students in schools would need to be provided with opportunities for integrating disciplinary knowledge and understanding, making use of teaching methods and approaches including scaffolding, modelling and explicit instruction, while maintaining a degree of independence, creativity and student ownership. We propose that the following types of activities particularly lend themselves to these ways of learning:

- experimentation and modelling;
- group work;
- argumentation, debate, and discussion.

By providing opportunities such as these (examples with context are provided in Table 1), students are encouraged to make *meaningful connections* between different disciplines to generate new questions that lead them to revisit the original purpose and re-analyse disciplinary knowledge. This is illustrated by the arrows in Figure 2. This is how we envisage the process of integration.

Synthesis

Through these opportunities for integration, reflection on purpose and task, and application of disciplinary knowledge and understanding, interdisciplinary synthesis evolves that is inherently metacognitive – a dynamic process of developing mental models through analysis, monitoring and evaluation. This is synthesis – the synergy that is achieved by interdisciplinary working (Figure 2). Synthesis could be evidenced by observation of the skills and ways of thinking suggested in Figure 1.

Interdisciplinary learning in a future curriculum

The Royal Society of Biology (2021), Royal Society of Chemistry (2020) and Institute of Physics (Tracy, 2018) have all published recommendations and frameworks for future curricula. All three approaches have been informed by *Principles and Big Ideas of Science Education* (Harlen, 2010). We have interrogated these four documents, and the Education Endowment Foundation's guidance report for improving secondary science (Holman and Yeomans, 2018), to make an assessment on the suitability and potential impact for using IDL in science teaching.

We have taken a holistic approach to our interrogation of these documents by looking at their underlying principles and fundamental ideas, and we believe IDL can be used to help realise and achieve the future vision of science education in the following four key areas:

- real-world application;
- equality, diversity, and inclusion;
- language;
- inquiry.

Real-world application

Including links to everyday life in science teaching is important for student engagement – the central theme for improving secondary science (Holman and Yeomans, 2018). Providing relevance in this way stimulates interest, supports progression towards understanding the big ideas in science, and gives opportunities to expose students to the ethical, social and political implications of science applications (Harlen, 2010). Exposing students to, and teaching them about, real-world examples is personally enriching and improves their understanding of new technologies and global issues (Royal Society of Chemistry, 2020; Royal Society of Biology 2021). It is also important for students to contextualise sciences to encourage the pursuit of related occupations, for example the relevance of physics to engineering (Tracy, 2018). Promoting positive and evidence-informed attitudes about science and developing scientific literacy is a key driver in meeting the aspiration of a science education suitable for all.

A real-world focus is central to our framework for IDL, and it is therefore a perfect platform for teaching students about the applications of science from all disciplines. Our framework also characterises the rigour of this learning approach and therefore avoids giving context by simply bolting on examples to existing teaching practice. Interdisciplinary working is itself a real-world process and learning in this way will promote problem-solving skills that are directly transferable to further study and the workplace.

Equality, diversity, and inclusion

There remains the need across science professions to continue tackling inequality and under-representation, and educators and learning experiences have an important role to play. Engagement promotes science as a subject and a career pathway for all students, whatever their background and aspirations (Holman and Yeomans, 2018). Equality, diversity, and inclusion can be promoted by challenging disciplinary stereotypes, which can be supported by broadening students' interdisciplinary perspectives. By exploring interdisciplinarity, students are not shackled within the confines of one discipline, and so they are free to move away from or to modify their perception of certain stereotypes. Our framework on IDL promotes group work, argumentation and discussion – learning processes aimed at developing the skills needed in real-world collaborations. Therefore, IDL can also teach students about the benefits that a diversity of contributions has in problem-solving and innovation. Contextualising scientific discoveries within history also helps students to understand where under-representation and systemic biases in the sciences come from.

Language

Communication is an essential skill for understanding the impact of science on the world and how scientific knowledge is used (Royal Society of Chemistry, 2020; Royal Society of Biology 2021). Developing specific scientific vocabulary through reading, writing and talk is important in improving teaching and learning in secondary science (Holman and Yeomans, 2018; Quigley and Coleman 2018). In addition, developing explanations and using argument and critique for reasoning are key skills required in scientific disciplines (Tracy, 2018). Developing oracy by providing students with opportunities to talk about science is also important in giving them the skills to discuss current real-world investigations (Harlen, 2010).

Our earlier discussion on integration in IDL centres around participation and discussion. IDL can provide more authentic examples of scientific debate and communication through role play and by providing a relatable context to students. In IDL, students can enrich their language and broaden their understanding of what vocabulary is relevant to science as they make meaningful connections with other disciplines, understanding similarities and nuances in language use, related to context. Well-designed IDL provides opportunities for quality questioning, a key component for developing language in the classroom, and it also plays a role in retrieval practice and in challenging misconceptions (Holman and Yeomans, 2018).

Inquiry

Inquiry is a key feature of effective pedagogy in science teaching, which involves providing activities for students to investigate, observe, explain, analyse and interpret (Harlen, 2010). It is important to teach students how we 'do science' and learn about scientific phenomena (procedural knowledge) and how practical techniques are used to provide valid and accurate evidence (Royal Society of Chemistry, 2020). Indeed, the sciences are empirical in their nature: explanations are derived from observations and experimental measurements (Tracy, 2018). Developing skills in data analysis and promoting the importance of mathematics and computational methods are essential for understanding how we study the biological world (Royal Society of Biology, 2021) and can be used to prove applicability to the task or purpose.

We argue in our framework that creating synthesis in IDL is a metacognitive process, which by definition is a conscious cycle of learning; it is suggested that making activities for inquiry conscious and visible enables students to develop their ideas about science, such as its implications and applications (Harlen, 2010). IDL creates an environment that encourages higher-level thinking skills (using analysis, synthesis, evaluation) that in turn define a process of inquiry.

Final remarks

We intend this framework to serve as guidance for teachers. It is important to recognise that imagination, innovation and specialist subject knowledge are at the heart of the teaching profession. IDL can be seen as a creative opportunity for teachers and learners, and this framework provides support and rationale for designing, planning and evaluating IDL.

We want to encourage teachers to experiment with IDL in 11–18 science classrooms. We hope to stimulate scholarly debate about the proposed framework and the suggested mechanism by which IDL is beneficial to learning. There is still a need to critically evaluate these ideas in theory and practice in order to build an evidence base and develop the model.

Acknowledgements

We would like to thank Ella Lee-Reynolds, Dr Ash Brockwell and Professor Carl Gombrich from The London Interdisciplinary School for informal discussions. We are also very grateful to Kirsty von Malaisé at King Edward VI High School for Girls for her support.

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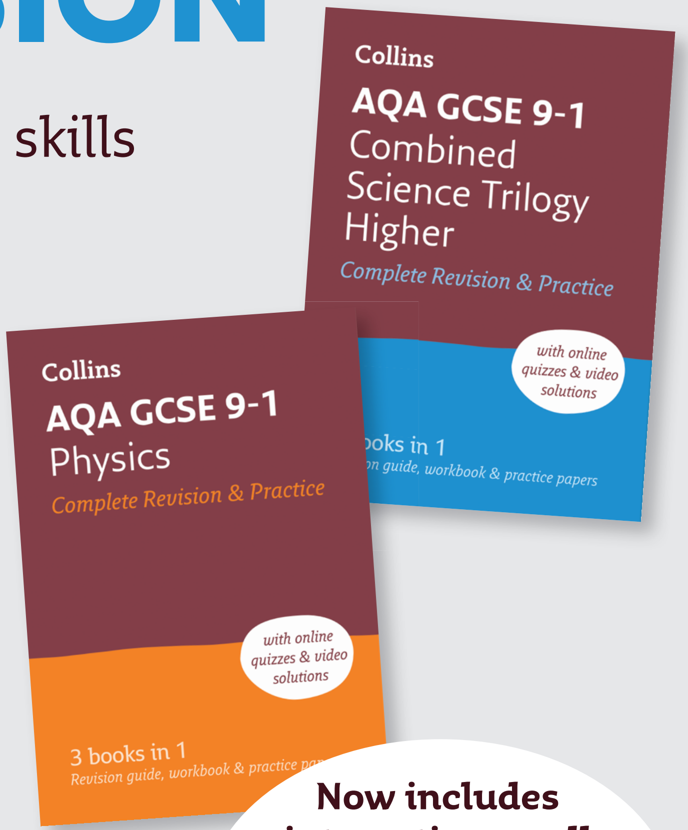

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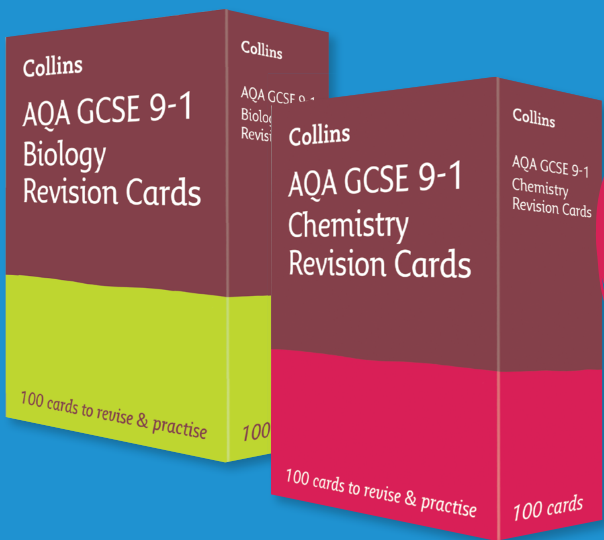

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