PILLARS AND LINTELS:
THE WHAT'S, WHY'S AND HOW'S OF INTERDISCIPLINARY LEARNING

Summary
Interdisciplinary learning (IDL) cannot be properly understood without a clear understanding of the nature, benefits and limitations of disciplines. Disciplines are branches of learning characterised by distinct objects, concepts, principles, theories, skills, tools and applications, and comprise groupings of 'like-minded' people. By ensuring depth of knowledge and understanding, disciplines give rigour and structure to the development of knowledge and understanding, and are characterised by their *transferability* and *applicability* to other areas of knowledge, contexts and disciplines.

Disciplines may also be inward-looking and fail to address new and relevant real-world problems, whereas major new insights and breakthroughs increasingly occur in interdisciplinary areas. In IDL learners draw on two or more disciplines in order to advance understanding of a subject or problem that extends beyond the scope of any single discipline. Successful IDL must be grounded in substantial disciplinary knowledge and understanding that is also transferable into different learning contexts. By contrast, multi-disciplinary learning involves the juxtaposition of disciplines and knowledge that may have no apparent connection and may be taught as separate entities around a theme or topic. Successful development and implementation of IDL will benefit from collaboration at all levels including sustained external support from universities, colleges, business and industry to provide CPD and clear and concise exemplification. The principles and practice of IDL apply across all areas of the curriculum.

Rapid scientific and technical innovation has irreversibly altered the demand for skills in an interconnected global marketplace. Employment growth will continue to favour highly-skilled, tertiary-educated workers. Skills are the global currency of the 21st century in which working life will become increasingly networked. Work will be increasingly variable and done on a project basis with contributors with complementary skills working in teams. These skills require development through a change of classroom practice and should be developed at all levels throughout education. This implies a shift towards inter- and multi-disciplinary knowledge and training.

The successful implementation of IDL in Scottish secondary schools with timetables and curricula designed around individual disciplines and disciplinary thinking is a major challenge in CfE. In primary schools one teacher will teach most or all subject disciplines but often with limited disciplinary knowledge. The development of STEM teaching in IDL contexts in primary schools, where few teachers have formal STEM training, is particularly critical. In secondary schools, common approaches to IDL delivery include school-timetabled IDL involving large-scale events for large groups (e.g. entire year groups) and classroom–based IDL, setting aside time for multiple disciplines to allow pupils to work on IDL projects within their normal daily timetable. However, the importance of considering IDL as a way of learning that is integral with rather than distinct from subject learning needs to be recognised. Beyond the formal curriculum and classroom, IDL has particular importance and potential in engaging disengaged and disadvantaged learners. Building links with employers and local communities in IDL projects supports their progress into training and employment.

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1. Curriculum for Excellence - The Four Contexts for Learning

Pupils, teachers and educators are now well versed in the *four capacities* of Curriculum for Excellence (CfE) – successful learners, confident individuals, responsible citizens and effective contributors. However, other than the familiar 'curriculum areas and subjects' the *four contexts for learning* are less well understood. The other three contexts are 'the ethos and life of the school as a community', 'opportunities for personal achievement' and 'interdisciplinary learning' (IDL). **Building the Curriculum 3** (*A Framework for Learning and Teaching*) stresses the importance of making connections between all four contexts, including within them extra-curricular activities and learning outwith the school (including outdoors learning). **Building the Curriculum 4** (*Skills for Learning, Life and Work*) further asserts that skills for learning, life and work should be developed across all areas of the curriculum in interdisciplinary studies, and in all contexts and settings where young people learn, while **Building the Curriculum 5** (*A Framework for Assessment*) states that achievement covers not only curriculum areas and IDL, but also other areas within and beyond the school. IDL thus assumes a central role within CfE in connecting the curriculum areas and subjects to these wider contexts and settings where young people learn, develop and achieve, thereby creating the potential to enhance systemically the development of all four capacities of CfE. Thus CfE represents a decisive move of education from its historical basis in successful learners, curriculum areas and subjects to a much broader and more all-embracing vision that encompasses its wider relationship to the community, the world of work and all contexts and places where learning takes place.

So what exactly is IDL, why is it important, what benefits for Scotland's future economy, culture and society will accrue from its implementation within CfE, and how will it be implemented in practice? The answers to these questions are not yet clearly and coherently articulated. The principles of IDL reviewed here in relation to STEM (Science, Technology Engineering and Mathematics) subjects are relevant and applicable across all areas of the curriculum and beyond, and as such it is important that they should not be considered as being peculiar to STEM.

2. What is Interdisciplinary Learning? View from the world of education and training

<u>Disciplines</u>

In order to understand the nature and principles of **interdisciplinary learning**, we require a clear understanding of the characteristics and importance of **disciplines**, and their benefits and limitations. Disciplines as a means of structuring educational and academic practice have been well established in UK education at all levels for over a century. A discipline is a branch of learning or domain of knowledge that is characterised by distinct objects, concepts, principles, theories, skills, tools and applications. Established disciplines, in schools, colleges, and higher education and research institutions alike, comprise groupings of 'like-minded' people with a shared language who subscribe to their principles and methods, interact with each other, and communicate and apply their knowledge and understanding in society, for example through education, research and economic activity. Although disciplines may be resistant to externally imposed change, they continuously evolve and develop from within as knowledge and understanding increase, especially in the STEM subjects. Their boundaries are not fixed and cannot always be easily defined. The accumulation of disciplinary knowledge leads to increasing internal specialisation and division.

Disciplines give **structure** and **rigour** to the development of knowledge, and are vital to sustaining and curating that knowledge and communicating it to non-experts and to future generations. Disciplines provide a reservoir of knowledge and skills that contribute personal, cultural, economic and social value to the well-being of society. STEM disciplines are characterised by their **structure** - concepts, principles, theories and methods - from which new outcomes and ideas emerge, predictions are made and theories tested. The more fundamental the idea or skill that has been acquired, the greater should be the breadth of its **applicability** to problems and its **transferability** to other disciplines. By contrast, if learning comprises unconnected knowledge, information or skills that are not placed within - or related to - a structured framework (such as a discipline) they are likely to be rapidly forgotten. Good teaching should impart an understanding of the underlying structure and principles of a subject rather than simply a mastery of facts and techniques.

There are also persuasive arguments against disciplines. The consistent focus on a single set of disciplinary phenomena may result in a lack of creative engagement with other disciplines and with the gaps between disciplines. Disciplines may be inward-looking and fail to address relevant, real-world problems. Learners may find it difficult to make links between disciplines. Disciplinary communities guard their boundaries in competition with other disciplines, yet it is in the gaps beyond disciplinary boundaries - the **interdisciplinary areas** - that major new insights and research breakthroughs occur. The 2014 Nobel Prize in Chemistry was awarded to three physicists working in biology laboratories to use fluorescence to visualize the pathways of individual molecules inside living cells ("nanoscopy"). Its main (breakthrough) applications are in medicine - a triumph of interdisciplinary working!

With the accumulation of human knowledge growing rapidly, particularly in the STEM disciplines, there is a doubling of knowledge about every decade. The result is increasing disciplinary specialisation in learning to the extent that we easily lose sight of the wider contexts and bigger picture, and of how ideas and phenomena interconnect and inform each other in a complex network of knowledge (McGilchrist 2012).

Interdisciplinary Learning

The terminology used to describe IDL is varied and confusing. The terminology adopted here draws on work of Chettiparamb (2007) and Harvie (2012). In **interdisciplinary learning** learners draw on two or more disciplines in order to advance their understanding of a subject or problem that extends beyond the scope of any single discipline. Learners integrate and develop information, concepts, methodologies and procedures from two or more disciplines to gain new knowledge, understanding and skills, and to explain or solve problems. **Contextual learning** is an important and widely used type of interdisciplinary learning where different disciplines or curriculum areas are focused - or converge - on a context, issue or problem. Contexts are typically practical, real-world problems or issues, such as for example climate change or energy. When the disciplines are in different curriculum areas, for example sciences and social subjects, this is often described as **cross-curricular learning**.

By contrast, **multidisciplinary learning** describes the **juxtaposition of disciplines** that may have no apparent connection or may be taught as separate entities by one teacher but related to a particular theme or topic (Harvie 2012). Simply linking or juxtaposing discrete subjects together around a theme is not by itself interdisciplinary (as defined above), but rather multidisciplinary. In good IDL, learners tackle relevant and meaningful questions or problems that will allow them not simply to make connections between two or more disciplines but also to draw on and develop their disciplinary knowledge, understanding and skills and thereby deepen their understanding of these disciplines (Harvie 2012). Only in these ways will IDL enable and enhance the vital capacity to transfer and apply disciplinary knowledge, understanding and skills to new problems and into other areas of learning. While multi-disciplinary learning is not in itself a bad thing, it may fail to convey this transferable and applicable disciplinary knowledge and understanding.

IDL cannot exist separately from disciplines but is fundamentally **founded on strong disciplinary knowledge, understanding and skills**. Furthermore, teaching specific topics or skills without clarifying their relationship to broader and more fundamental principles (starting from the specific rather than the general) makes it difficult for learners to transfer and generalise their learning to make it useable beyond the situation in which the learning occurred. Students undertaking IDL obtain a deeper understanding of the links between disciplines, the transfer of learning and the inter-relationships of phenomena.

Interdisciplinary learning – the pros, the cons and the evidence

Successful interdisciplinary working has largely developed in research in universities and industry from *within* STEM disciplines in response to the recognition that major advances in STEM research typically occur at disciplinary interfaces, where progress depends on making interdisciplinary connections and gaining new insights. This usually requires **teamwork and collaboration** amongst people from two or more disciplines, a practice common in industry and the workplace. Education should reflect such practice.

The practice of IDL stimulates **curiosity and motivation** and develops awareness of wider career opportunities**.** In STEM education, there is a perceived need to stimulate the **prior interest** of learners in the material to be learned by emphasising its relevance to practical everyday problems, many of which require interdisciplinary approaches. If learners are interested in a problem they are more likely to become interested in the underlying science.

Creativity – having original ideas that have value (Robinson 2011) **-** is widely regarded as the highest order skill in Bloom's Taxonomy. It is the foundation for **innovation** – the process of putting ideas into practice. Creativity usually happens when we make unusual or novel connections, bring together ideas or ways of looking at the world not previously related or connected, combine ideas in novel or unusual ways, or solve questions or problems not previously considered to be associated. It is a move away from linear thinking towards systems thinking. Creativity is therefore usually founded on – and fostered by - interdisciplinary (including cross-curricular) working, systems (or holistic) thinking and (in the 21st century) team working. **IDL promotes creativity and related higher-order thinking skills**.

In public perception, creativity is usually considered to be associated with the arts, particularly the so-called 'creative' or performing arts, such as music, drama, dance, writing etc. This is a false but unfortunately widespread perception. Creativity is possible in any and every discipline, not just in the creative arts, and is by no means confined to 'academic' pathways of learning. Creativity is as central to STEM subjects, and to enterprise, innovation and economic success as it is to other areas of human culture. Narrow educational curricula and cultures that create boundaries between curriculum areas and subjects (for example between arts, STEM and social subjects, or between STEM disciplines) are likely to inhibit innovation and creativity.

The delivery of IDL is also commonly associated with diverse types of learning such as **co-operative, problem-based and contextual learning**. In implementing problem-based IDL, teachers become facilitators, supporting pupils to become self-directed learners, and through co-operative learning working to share their learning with others. Research evidence on the advantages of co-operative learning and debates around the benefits of IDL is reviewed by Harvie (2012).

The benefits that interdisciplinary and cross-curricular learning confer on learners within and beyond the STEM disciplines have been widely recognised and welcomed, but research evidence for the effectiveness of IDL in school education is as yet limited (Howes et al 2014). Hurley (2001) has shown show that student achievement in science was greatest when maths was used in integration with science or to enhance science, and in maths when taught in sequence with science (i.e. planned together but taught separately). Riechert and Post (2010) showed that enrichment activities involving IDL work have positive effects on learners' interest in and attitudes to STEM. There is little evidence of interdisciplinary STEM in education systems in countries with a heavy reliance on individual subject examination, whereas countries that encourage a broader range of subjects post-16 including maths or science tend to get higher participation rates in STEM. Further research evidence on the impact of IDL on learning is summarised in the BOCSH Report (2015) and the STEMEC Report (2106).

Progress in development of IDL in Scottish school education is slow and patchy (STEMEC Report 2016). Perhaps surprisingly, despite the strong development of interdisciplinary working in research in HEIs, there is also concern about the slow development of IDL in teaching in higher education, where attitudes appear to remain stubbornly conservative (Wernli and Darbellay 2016; Lyall et al 2016). There appear to be strong parallels in IDL development and implementation in both school and university learning and teaching. The concerns expressed with limited progress in IDL development in HEIs would be addressed if students entering tertiary education were already interdisciplinary learners and thinkers. A systemic approach to IDL implementation is recommended.

Pillars and lintels – a balanced perspective

While strongly supporting the intention of CfE to develop IDL, the SEEAG Report (2012) concluded that *Interdisciplinary working requires that all science subjects should continue to be founded on deep and coherent pillars of knowledge and understanding. Interdisciplinary understanding will lack rigour and utility if it is not part of a structure in which the disciplines are pillars with interdisciplinary work as lintels. Without the pillars, the lintels will fall*. In other words, to be of long-term value the delivery of interdisciplinary learning must provide substantial rigorous disciplinary knowledge and understanding that is transferable into different contexts. How this balance is to be achieved in practice is a grand challenge of CfE that has yet to be confronted.

Successful development and delivery of IDL within CfE is strongly dependent on teacher skills, classroom organisation and practice, a deep understanding of the *nature* of IDL and its relation to the disciplines, a sufficient breadth and depth of subject knowledge, understanding and skills, and expertise in curriculum design. Practical logistical issues for schools (discussed below) include timetabling, cost, time and collaboration across subjects and departments.

All these challenges will require a high and sustained level of support through CPD, development of professional learning communities (PLCs), development in initial teacher education (ITE) and more on-going **collaboration** between schools, local authorities, universities and colleges, business, industry and other agencies. In other words, **change needs to be systemic**. Teachers need the time to think, plan and collaborate to develop IDL. Good exemplification of IDL is in short supply and is urgently needed. Tackling these challenges through the creation of strong, interconnected and **collaborative support systems** and the establishment of **creative partnerships** can create a roadmap to enable Scotland to be a world leader in interdisciplinary learning. The development of a **culture of collaboration** at all levels in Scottish education, at classroom, school, regional and national level, was a key cross-cutting theme of the STEMEC Report (2016), the OECD Report (2015) and the Report of the Initial Findings of the International Council of Education Advisors to Scottish Government (2017).

3. Why is IDL important? View from the world of work

Education has four broad aims – economic, personal, cultural and social. Pupils and their parents, teachers and employers, governments, taxpayers and other stakeholders will all want to be convinced about the benefits that a new emphasis on IDL within CfE will bring. Will the employment prospects of young learners be enhanced and their life experiences enriched? Will IDL implementation help to stimulate creativity, curiosity, aspiration and enterprise, make Scotland more economically competitive and bring wider social and cultural benefits?

Fundamental shifts in the nature and structure of employment in developed countries have led to a decline in agriculture and manufacturing and growth in services. In manufacturing there has been a shift to the development and production of high value goods. The number of higher skilled professional, technical and managerial jobs has risen at the expense of routine, lower-skilled employment. Rapid scientific and technological innovation have been the principal drivers of change in a connected global marketplace in trade, supply, finance, information, skills and knowledge exchange, generating widespread benefits through improved living standards but also greater complexity across economic systems, and with it economic, social and environmental vulnerabilities and potential for major job losses, especially where automation has made a major impact. These changes have irreversibly altered the demand for skills, with a shift away from routine cognitive and craft skills and physical labour. Scotland must now compete in international marketplaces on an entirely different basis, with leading emerging economies poised to overtake the OECD economies through more rapid growth.

Employment growth will continue to favour highly skilled (tertiary-educated) workers. The boundaries between manufacturing and service sectors will blur and greener technologies and practices will diffuse across economies. Long-standing structural weaknesses in the UK economy reflect years of inadequate investment in skills, infrastructure and innovation, with a long post-industrial legacy of educational and social inequity. If the UK could raise educational standards to those of recent leaders such as Finland it could add more than £8trn to GDP over the lifetime of a child born today, equivalent to one percentage point on annual growth (CBI). Improving the quality of school education is a key growth and investment issue. The widely-sought social dividend that improvements in human capital achieve through raising educational performance nationally directly addresses the enduring challenge of educational, economic and social inequity.

The complexity of the challenges and problems facing mankind in the 21st century require a global response. Global problems do not exist in isolation, and an attempt to solve one problem may exacerbate another (Weil 2014). Learners need to be able to understand complex, interconnected problems and systems and to collaborate to solve problems. In particular, learners need to learn how to question and to impartially evaluate complex and contrary evidence.

This is the world in which we now live and work. What are the implications for education and skills in general and for STEM education in particular? Skills have become the global currency of the 21st century and are the key to translating creativity, curiosity and innovation into economic growth and employment. Emerging economies have made substantial long-term investment plans for education and skills development. By contrast, for developed economies with ageing demographics such as Scotland the need to ensure that their human capital keeps pace with rapidly evolving skills demands of labour markets is particularly acute.

Working life in 2020 will be even more networked, and jobs less routine. Work will increasingly be done on a project basis in collaboration with various contributors with complementary knowledge and skills, and tasks will become more variable. A developing 'on-demand' economy will favour 'freelance' workers able to master and sustain multiple skill sets, and job flexibility will replace job security. An ability to apply network skills is the foundation of future work; network skills find their application in the ability to find, use, connect and disseminate knowledge, to identify new opportunities and find solutions to problems. Many of the most commercially significant innovations in industry and business are expected to result from cross-disciplinary fertilisation. The key to success is the ability of people with different competences to work together in teams, learning from one another and building on existing ideas. These skills require practice, involve development of both the curriculum and teaching/classroom practice, and should be developed throughout education at all levels through what we teach and how we teach it.

An OECD report identified the following key elements as essential in 21st century education systems in relation to skills and employment:

<u>Knowledge:</u> - relevance, real-world experience, rethinking of the significance and applicability of what is taught to strike a far better balance between the conceptual and the practical.

<u>Skills:</u> - higher-order skills, such as creativity, critical thinking, communication and collaboration are essential for absorbing knowledge as well as for work performance, requiring expertise in combining knowledge and skills in a coherent ensemble.

<u>Character</u> (behaviours, attitudes, values): to face an increasingly complex world it is important to teach character traits, such as performance-related traits (adaptability, persistence, resilience) and moral-related traits (integrity, justice, empathy, ethics).

Demand for STEM skills is particularly high, both within STEM-based industries and in businesses and beyond. Many growth sectors are STEM based, with a high projected demand for *both* high-level STEM skills and more generic skills. Two thirds of businesses responding to a recent SCDI/Skills Development Scotland (SDS) survey identified the need for a greater focus on STEM subjects across the education and training system, emphasising leadership, planning and organising, team work, strategic management, technical and practical skills, advanced IT and software skills, plus improved written and oral communication skills.

The characteristics of good IDL coupled to modern classroom practice within CfE map very naturally onto the economic, employment, social and cultural environment of the 21st century. A new and higher-level inter- and multi-disciplinary knowledge base will be essential, with a shift away from narrowly focused specialists to flexible individuals with interdisciplinary academic training. In key areas such as STEM-related subjects there is a more general emerging skills need for interdisciplinarity within the science, technical and business areas, for which teachers will need to be able to combine approaches to teaching, work collaboratively internally and externally, and acquire strong technology skills. Specifically:

- Businesses will require young people with flexible skills and the ability to innovate and cope with change and learn continuously throughout life; knowledge transfer is as much about communication as specialist skills.
- Schools must stimulate a child's ability to solve new, non-routine problems, combine different bodies of knowledge and interact productively with others, which is essential if individuals are to become competitive in the globalized economy.
- Active learning based on student participation, experiential learning models and learn-by-doing approaches will matter more than passive approaches.
- Core skills should be delivered in a way that excites and engages learners.
- Skills development is more effective if the world of learning and the world of work are linked. Learning which incorporates work-related case studies and simulations and learning in the workplace allows young people to develop both "hard" and "soft" skills, with real-world relevance and experience. It is apparent through SCDI's network of Young Engineers and Science Clubs that industry-set school challenges from a range of sectors are usually designed to require teamwork and an interdisciplinary approach.
- In STEM, students should be encouraged to run their own experiments, involving more open-ended questions and more organised group activity.

Feedback from SCDI members in STEM-related sectors supports IDL, but businesses requires more definition of what IDL means if it is to be made meaningful. Bad IDL is seen as probably worse than no IDL. Good IDL needs to be respected and embraced by teachers, students, and employers. However, the teaching of core skills and disciplinary knowledge must not be lost.

4. How can IDL be delivered? View from the classroom and beyond

In Scottish secondary schools timetables are designed around subjects so do not easily accommodate delivery of IDL. By contrast in primary schools one teacher will usually teach across most subjects within CfE, and challenges in delivering IDL are around teacher confidence, subject knowledge and maintaining disciplinary rigour across the curriculum. So how are secondary schools delivering project/challenge based IDL? Two common approaches appear to be emerging in school-timetable based IDL, while STEM clubs (including Young Engineers and Science Clubs) provide additional projects and challenges for pupils that are set in real life contexts and usually draw on STEM as well as non-STEM disciplines (i.e. cross-disciplinary). However, the high quality of many STEM club projects or challenges is evident and teachers may wish to look at the SCDI Young

Engineers and Science Clubs website for examples and further information. Support is also available from STEMNET, through for example the STEM ambassador programme. A few schools opt for a mix of approaches to IDL and no one method should be seen as perfect.

1. Large scale events

In full-day IDL events a School will arrange for an entire year group to be out of class at the same time. The group will be set a task or project that has an IDL theme. Pupils will then work in a hall or with specific subjects throughout the day in order to complete their project. This could for example be a forensic activity or a natural disaster aid mission. The benefit of such work is the experience for the pupil, and the prospect of being out of class for a day in a new working environment is clearly appealing to pupils. Some points to consider for this method are: How is disciplinary rigour maintained? How will you ensure that pupils recognise the contribution of each discipline to the overall project or challenge? Does this project relate to career opportunities and skills required for the future? Can the event be sustained in the longer term and thus be adapted and developed year on year to fine-tune improvements (particularly if the event involves external partners)? Does an event of this scale allow personalisation and choice as well as differentiated support for pupils?

2. Classroom based IDL

In classroom-based IDL, management will set aside time for multiple disciplines to allow pupils to work on IDL projects within their normal daily timetable. To achieve this, two or more departments will collaborate to develop an IDL project or challenge and determine how much time 'off timetable' (i.e. outwith their usual CfE lessons) subject disciplines require to spend on the work. Alternatively a school may decide to select an existing STEM challenge, for example to take part in the Junior Saltire competition. This would require lessons to be developed and delivered in a variety of subjects including for example science, CDT, computing, English and maths, with the teachers selecting a 'lead' subject that which will launch the project/challenge at the start and pull together the project at the end. There are clear advantages to this model in that it allows greater opportunities for differentiation, learners recognise each distinctive disciplinary contribution to the overall project, learners can identify areas of the curriculum where they are succeeding or require improvement, and teachers can ensure and assess individual discipline work based on prior learning as well as contribution to overall project based on well defined success criteria. When organised and in place there is less impact on the normal school day and the project can be run year on year.

Some points to consider with classroom-based models are: How much development time will be required by teachers to ensure each discipline is ready? Which will be the lead discipline? Would it benefit learners to launch the project during an assembly? How much time and space will be needed to bring the project together at the end so that pupils can showcase their work? What will be the success criteria at the start of the project and how will this be embedded with relevant skills and CfE Curriculum experiences and outcomes? How can the project be developed to ensure that pupils can be creative?

IDL should not involve random subject collaborations dictated by a pre-existing timetable, or rebranding and 'bolting-on' of existing materials. Good IDL requires faculty ownership, identifiable budgets, timetable priority, preparation and assessment. Additional FTE costs of collaborative working should be recognised. Disciplinary knowledge should be evident to learners and not lost within the interdisciplinary learning context. Anecdotal evidence from primary STEM IDL (Beveridge, pers comm) highlights the dangers of the science getting lost within the project context or narrative to the point that learners do not recognise that they have learned any science. There may be areas of science that are better taught as more traditional disciplinary science rather than within IDL projects and contexts. Experience and good judgement are required.

3. IDL Beyond the Classroom: Engaging Disengaged Learners and Bridging the Attainment Gap

Poverty is a prime cause of educational disengagement and disadvantage. Many countries are trying to close the gap in educational attainment between their poorest and richest pupils, and between schools in the most and least deprived areas. Improving educational attainment is now a top priority of Scottish government. With more than one in five children in Scotland recognised as living in poverty, significantly higher than other European countries (Scottish Government 2014), by the age of 5 children in poverty lag between 10 and 13 months behind their more affluent peers in attainment and school readiness (Sosu and Ellis 2014). Identifying new ways of engaging disengaged learners is one of the challenges of 21st century education, one that is of fundamental importance to the improvement of Scotland's workforce.

Beyond the formal curriculum and the classroom, IDL as a component of school improvement has particular relevance to the challenge of engaging disengaged learners, providing alternative ways of encouraging them to participate actively in their learning. IDL encourages team building and other soft skills and values such as resilience, resourcefulness, reflectiveness and reciprocity that will benefit all pupils, but especially the disengaged. Providing an alternative curriculum and engagement with employers increase the likelihood of disengaged pupils progressing to employment or training (Kettlewell et al 2012). Employers may become co-investors and co-designers of IDL projects, contributing to creating greater parity of esteem between academic and vocational sectors (Scottish Government 2014). Implementation of IDL creates an extra dynamic within the school system, building a rapport between staff and sharing resources between departments, and promoting an ethos of shared responsibility.

Group work on real-life scenarios encourages creativity and the use of literacy, numeracy and IT skills across the curriculum and beyond, and encourages collaboration and team building. Links between schools and local communities and employers develop an awareness of careers and life beyond school. It is here that IDL, the life of school as a community, and personal achievement converge, just as anticipated by the four contexts for learning of CfE. Schemes such as the John Muir Award can provide additional motivation, personalisation and aspiration, promoting a 'hands-on' approach involving designing, building, creating – all higher-order thinking skills.

4. Learning in an interdisciplinary way

A key question about the fundamental nature of IDL, which has important implications for its delivery and assessment, is whether IDL is in essence simply a way of learning – *learning in an interdisciplinary way*. Yet approaches to delivery of IDL discussed above may imply that it is distinct from subject learning and should be delivered as such, whereas it could and should be considered as a natural and complementary approach – or extension – to subject (disciplinary) learning. The importance of IDL as a way of learning that is integral with - rather than distinct from - subject learning needs to be recognised. This in turn presents a dilemma for the wider understanding, implementation and assessment of IDL. In order to promote understanding and implementation of IDL, it may be helpful for learners and teachers to undertake IDL initially as something distinct from disciplinary learning. The importance of seeing IDL as a way of learning that is integral with - rather than distinct from - subject learning needs to be recognised in its implementation. Exemplification of IDL in various curriculum contexts is therefore a key element of its development within the Scottish curriculum.

5. Exemplification of IDL

The pressure on teachers to implement CfE and progressively deliver the new qualifications has been severe. Nonetheless, IDL is one of four contexts for learning on which CfE is founded. Implementation of IDL remains at an early stage and is currently the subject of a national programme of action (see below). In order to both articulate and exemplify the nature of IDL and at the same time provide teachers and schools with valuable interdisciplinary and cross-curricular materials and resources, high-quality, practical resources are required that touch on all areas of the curriculum, encourage a culture of collaboration across disciplinary boundaries both within and schools and school clusters, and develop sustainable cohorts/groups of teachers in schools that are able to provide leadership in the progressive implementation of IDL.

Some Case Studies

A. Carbon Capture and Storage (Scottish Earth Science Education Forum (SESEF); SCDI Young Engineers and Science Clubs (level 3 Workshops)

(Graham 2014; www.yecscotland.co.uk/secondary_school_resources.html)

- Topical inter-disciplinary investigation of the science and technology underpinning the generation, transport and underground storage of carbon dioxide, and the rationale in relation to climate change.
- Hands-on co-operative learning involving investigative role-play, leading to the construction of a miniature working carbon dioxide storage facility.
- Disciplinary science and technology elements include combustion, properties of carbon dioxide, behaviour of gases at high pressure (Boyle's Law), properties of rocks (porosities), effects of carbon dioxide on aquatic life (pH), power generation (generators and turbines).
- Incorporates numeracy and literacy elements and is supported by animations.
- Delivered and evaluated in several different models and contexts, including teacher CPD, classroom delivery in secondary schools with cascading to feeder primaries, and pupil-led events at Edinburgh International Science Festival. Currently (2016) licensed to Young Engineers and Science Club (SCDI) for delivery across Scotland, and to four educational trusts across England and Wales.
- Funded by industry (Scottish Power, OPITO, Shell) and Scottish Government.

B. Peat Bogs and the Flow Country (SSERC and SESEF (University of Edinburgh)) http://www.sserc.org.uk/index.php/environmental-science/3840-peat-bogs-and-the-flow-country

C. Sea Level Change (Geosciences, University of Edinburgh) – www.open.ed.ac.uk

6. IDL National Strategy Group

A long-term national programme of action supporting the development and delivery of IDL in STEM subjects has been established, bringing together representatives from key agencies and organisations across Scottish education in a National Action Group. Its purpose is to agree the principles, conditions and support necessary to enable teachers to deliver and sustain IDL in Scottish education and, working in partnership, to implement these, building on existing good practice and thus improve young people's learning experiences and help them to develop the skills they will need in their further training and careers. Successful reform of learning, teaching, curriculum and assessment that includes IDL as a context for learning requires vision and systemic change, and this occurs only on decadal timescales.

A more extensive in-depth exploration of the nature, development and impact of IDL is contained in the STEMEC Report (2016).

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This review paper draws extensively on the work of Bruner (1977), Chettiparamb (2007), Harvie (2012), Kline (1995) and the SEEAG Report (2012).

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