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EFFECTIVE STEM TEACHING AND LEARNING TO ADDRESS FUTURE CHALLENGES

Event Report

Background and Introduction

Science, Technology, Engineering and Mathematics (collectively called STEM) are instrumental to advancing our fundamental understanding of the world around us and play critical roles in helping us respond to the complex challenges that society is faced with today. Primary and post-primary curricula that integrate teaching and learning of STEM disciplines are increasingly common and are aimed at equipping the next generation with the required theoretical and practical knowledge, skills, attitudes, and values to address societal challenges and to help them live justly, sustainably and with regard to the rights of others.

However, some barriers appear to be inhibiting effective STEM teaching and learning in classrooms worldwide. These include limited definitions of what STEM education comprises and a dearth of research-informed pedagogies to support teachers in implementing effective integrated STEM in classrooms. Furthermore, research literature suggests that integrated STEM approaches may risk side-lining the discrete disciplines of STEM, which could result in limited disciplinary understanding. Concerns have also been raised regarding teachers' knowledge and skills in integrated STEM teaching, as well as the need for tried and tested educational resources and clear assessment criteria.

To address these and related issues, ALLEA (the European Federation of Academies of Sciences and Humanities) and the Royal Irish Academy (Acadamh Ríoga na hÉireann) organised the symposium "*International Reflections on STEM Education - Effective teaching and learning to address future challenges*" on 25 October 2022 in Dublin. This Event Report summarises the views expressed during the discussions – the full programme of the symposium can be found here.

From Siloed Disciplines to Integrated STEM Education

Central arguments for integrating STEM subjects include the desire to provide future generations with the requisite knowledge, skills, attitudes, and values to enable them to address complex real-world problems, and to engage them with experiences in STEM that are relevant to their everyday lives and surroundings. Facilitating such natural connections and encouraging a flexible use of knowledge and skills helps develop young people's ability to reflect and to apply what they have learned in STEM classes with their everyday lives outside of school. There appears to be widespread support amongst policymakers, teachers, and parents for adopting integrated STEM education curricula, but classroom implementation is limited and often challenging.

At pre-school levels, when STEM is taught, integrated approaches to teaching and learning about STEM related topics are the norm – experienced early-years teachers directly respond to the activities and interests of children by providing the right knowledge and learning opportunities through integrated STEM approaches. Such flexible approaches are particularly effective in the early learning years, but frequently these kinds of integrated, child centred approaches do not transfer to the more formalised primary and post-primary school environments, which are often bound by curricula and assessment criteria.

A broad spectrum of discipline-focused and integrated STEM education models coexist (see Table 1), each coming with its own advantages and limitations. In practice, at times it can be difficult to obtain a good balance across all disciplines in integrated STEM approaches. There are concerns also about teacher knowledge, beliefs, and confidence in adopting integrated STEM education in classrooms. Research suggests that tensions exist for teachers in balancing the demands of subject specifications in disciplinary content knowledge development that guide discrete STEM subject teaching, with what are sometimes perceived as the more uncertain, or perhaps less easily quantifiable knowledge, skills and values gleaned through integrated STEM teaching (Hourigan et al 2021).[1] Concerns for the side-lining of Science content and processes within a rush to integrated STEM have also been raised.[2] These concerns pose problems for teaching and learning STEM in both disciplinary and integrated ways.

In a bid to offer the 'best of both worlds', combinations of disciplinary and integrated approaches are frequently utilised. For example, in Ireland, STEM subjects are taught in an integrated fashion at early stages of the primary curriculum, whereas in upper primary and secondary levels, these are broken up into Science & Technology and Engineering & Mathematics. In other countries, STEM subjects are predominantly taught separately and integrated through inquiry-based projects. The international landscape of STEM curricula is very heterogeneous, and one can find different variations of multi-, inter-, and trans-disciplinary approaches. A comprehensive assessment of how they link to the desired outcomes is currently lacking and will be essential for further development of curricula and teaching materials.

Disciplinary	Concepts and skills are learned separately in each discipline
Multidisciplinary	Concepts and skills are learned separately in each discipline but within a common theme
Interdisciplinary	Closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills
Transdisciplinary	Knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus helping to shape the learning experience

Table 1. Varieties of STEM integration.[3]

1 Hourigan, M., O'Dwyer, A., Leavy, A.M., & Corry, E. (2021). Integrated STEM – a step too far in primary education contexts? *Irish Educational Studies*. https://doi.org/10.1080/03323315.2021.1899027

2 McComas, W.F., Burgin, S.R. A Critique of "STEM" Education. *Sci & Educ 29*, 805–829 (2020). https://doi.org/10.1007/s11191-020-00138-2

3 Adapted from: Vasquez, J., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, Grades 3–8: Integrating science, technology, engineering, and mathematics*. Portsmouth, Heinemann Publishing. https://www.heinemann.com/products/e04358.aspx

Education Centred Around Real-World Problems

A possible reason why effective integration of all four STEM subjects is so challenging could lie in the widely differing nature, pedagogies, and philosophical basis of the four disciplines.[4] Instead of assuming that the four STEM subjects always and exclusively belong together, it was noted during the symposium that (1) each subject has its unique values and epistemologies and (2) their integration in inquiry-based education should reflect the nature of the problem to be addressed.

It was broadly agreed that the interdisciplinary nature of complex real-world (wicked) problems goes beyond the STEM disciplines – for example, poverty, climate change, inequality, food & water security, biodiversity loss, homelessness, sustainability. This is also reflected by the introduction of expanded STEM acronyms, such as STEAM (where "A" stands for the Arts) or STREAM (where "R" stands for Robotics).[5] These expanded acronyms, however, still presume a degree of rigid clustering of a limited selection of subjects, whereas most of the challenges we are faced with today should be approached from the broadest socio-scientific perspective. Truly holistic curricula should therefore also take political, societal, and cultural developments into consideration and include subjects from the social sciences and humanities. Such approaches should be supported by further integrating ethics, social responsibility, values, and attitudes.

To navigate an information-rich digital world, it will be key to develop the skills to critically evaluate scientific information.[6] This requires that children not only acquire content knowledge, but also "procedural knowledge" (knowledge of the practices and concepts on which empirical inquiry is based) and "epistemic knowledge" (understanding of the role of specific constructs and defining features essential to the process of knowledge building in science).[7]

When developing integrated curricula, further notice should be taken that:

- Digital technologies can be used to greatly expand real-world learning experiences when used in a meaningful way, but a systemic approach is needed that addresses teaching and learning at different levels: policy, research, curriculum design, teacher education, and practice.[8]

- Diversity, equity & inclusion (EDI) should be central in the development of new curricula and teaching materials. EDI should be approached in the broadest possible sense, considering age, ethnicity, gender/sexuality, religion, geography, socioeconomic background, etc.

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4 For example, Mathematics can be considered "rationalist", and teachers care about the hierarchical structure of their subject and progression thereof in their teaching. Technology and Engineering, on the other hand, can be characterised as "pragmatist", with curricula consisting of serial problem-solving projects that each require particular knowledge and skills. Finally, Science combines such hierarchical and horizontal elements and uses an "empiricist" approach to explain the physical world. See: Reynante, B.M., Selbach-Allen, M.E. & Pimentel, D.R. (2020). Exploring the Promises and Perils of Integrated STEM Through Disciplinary Practices and Epistemologies. *Sci & Educ 29*, 785–803. https://doi.org/10.1007/s11191-020-00121-x

5 The STEM acronym itself could be considered biased towards certain languages and countries (it is for example called MINT in Germany and LUMA in Finland), which may prevent wider uptake of the acronym and the underlying pedagogies.

6 European Commission (2022). *Guidelines for teachers and educators on tackling disinformation and promoting digital literacy through education and training*. https://op.europa.eu/en/publication-detail/-/publication/a224c235-4843-11ed-92ed-01aa75ed71a1

7 See also: *Competence Domains*. PISA. https://www.pisa.tum.de/en/pisa/competence-domains/

8 See also: ALLEA (2022). *Statement in Response to the European Commission's Call for Evidence on Digital Education and Digital Skills*. https://allea.org/portfolio-item/allea-statement-digital-education-digital-skills/

- Linguistic understanding is essential to grasping any STEM concepts and to developing the skills for dealing with complex real-world problems. Although this may seem obvious, the need for appropriate language skills is often overlooked in the development of integrated STEM curricula.

It will be key to ensure that any curricular reforms are supported by solid empirical evidence in relation to teaching and learning. Ultimately, teachers should have access to a breadth of thoroughly validated teaching materials for them to respond to their learners' needs and interests.

Primary Initial Teacher Education and Teachers' Professional Learning

A persistent problem within initial teacher education (ITE) for primary school teachers is that there is insufficient time for developing the required pedagogical tools and disciplinary knowledge to support primary teachers to teach STEM subjects confidently and competently. This is of particular concern as, frequently, students entering primary ITE have not taken STEM subjects at second level, resulting in many of them not having a strong background in these subjects. It is therefore crucial that additional time is allocated on ITE programmes to support future primary teachers in developing their conceptual and pedagogical knowledge in STEM.

Teaching integrated STEM approaches puts a further pressure on already full ITE programmes and it cannot be assumed that teachers will acquire all the requisite knowledge and skills during their ITE programmes to support them in effectively implementing STEM approaches. To address this issue, teachers could be afforded co-teaching opportunities as part of ITE programmes that would enable them to develop a good level of STEM fluency.

Throughout their careers, time and resources should be made available for teachers to undertake immersive professional learning experiences and engage in collaborative work with their peers. The simultaneous existence of subject-specific and integrated STEM curricula, each with their own objectives and assessment criteria, can be difficult for teachers to navigate. Access to educational resources and examples of good practices are often limited and opportunities for exchange should be provided between teachers from different schools, regions and even internationally.

New policies and visions for curricula and pedagogies do not automatically reach teachers and classrooms, and require continuous interactions between teachers, researchers, and policymakers. Rather than considering teachers as curriculum brokers, they should be provided with the responsibilities and, importantly, skills and resources to take a more active role as curriculum developers.

Taking a Step Back – What is the Purpose of Education?

The presumed natural alliance of STEM subjects was contested by participants of the symposium. Rather than thinking in silos (being either individual subjects or narrowly and arbitrarily defined clusters of subjects) more holistic teaching and learning approaches need to be considered. Currently, curricula have a strong focus on fulfilling assessment objectives and criteria. This inhibits the creativity and freedom for improvisation that is required to respond to the needs and interests of children, as well as for adapting to the rapidly changing nature of real-world problems and their local nuances. Any form of interdisciplinary education should mean that links between subjects are made clear to teachers and learners and that they develop the skills to make such links independently, both in the classroom and in real-world problem solving. Seeing teachers as curriculum developers would allow them to bring in knowledge and skills from the arts, humanities and social sciences to more truly reflect the complexity of the challenges facing society.

Over the past decades, curricula have undergone various transitions, moving away from a traditional focus on collecting knowledge, via an overemphasis on acquiring competences, to a more balanced relation between the two. Before thinking of new policies and curricula, we may have to take a step back and have a more fundamental dialogue about the purpose of education. Perhaps, rather than asking ourselves "*what should the future generation know?*" we should focus on the question of "*who do we want people to be?*".[9]

About ALLEA

ALLEA is the European Federation of Academies of Sciences and Humanities, representing more than 50 academies from over 40 countries in Europe. Since its foundation in 1994, ALLEA speaks out on behalf of its members on the European and international stages, promotes science as a global public good, and facilitates scientific collaboration across borders and disciplines. Learn more: www.allea.org

About the ALLEA WG Science Education

The ALLEA Working Group Science Education is committed to supporting the further progression of science education throughout Europe to ensure the development of the necessary knowledge, skills, and motivation of students to pursue careers in science and participate as active and informed citizens. Central themes of the group include climate change education, science education in the context of STEM curricula, and digitalization in science/STEM education. Learn more: www.allea.org/science-education

About the Royal Irish Academy

The Royal Irish Academy (Acadamh Ríoga na hÉireann) was founded in 1785 and is Ireland's academy for the sciences, humanities and social sciences. The Academy provides expert advice, manages research projects, publishes books and journals and sustains a library. Election to membership of the Academy is the highest academic honour in Ireland and the Academy has currently approximately 500 members. Learn more: www.ria.ie

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9 Biesta, G. (2020). Risking Ourselves in Education: Qualification, Socialization, and Subjectification Revisited. *Educ Theory*, 70: 89-104. https://doi.org/10.1111/edth.12411