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Technology and Engineering Education Standards in an Innovative European Collaborative STEM Project: Lessons from Ireland and Sweden

Abstract

This chapter will describe a project that aims to provide teachers and students with necessary and efficient digital assessment approaches for the development of students' transversal skills in STEM education. These approaches were developed, implemented, and evaluated through large-scale classroom piloting, leading to policy recommendations at national and European level for the further transformation of education. This international project included partners from Austria, Belgium, Cyprus, Finland, Ireland, Slovenia, Spain, and Sweden and was co-funded by partners and the European Commission under its Erasmus+ KA3 Policy and Experimentation initiatives.

The aim of this innovative policy experimentation project was twofold. On the one hand, to "know and explain" the process of implementing the ATS STEM program and, on the other hand, to "understand" how it works in different contexts (schools, classrooms, countries) and thus make suggestions for improvement.

This chapter will attempt to provide an overview of the commonalities and differences among the national standards in the countries involved in the ATS STEM project and compare them to

the context of the *Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education* (STEL).

References: ATS STEM http://www.atsstem.eu

Keywords: STEM education, technology education, engineering education, experimental

Introduction

There are many frameworks that have been developed to try to comprehend STEM education as an emergent interdisciplinary area of study (McLoughlin et al., 2020). H However, STEM as a unified entity never quite seems to achieve the goal of true integration. The individual disciplines that comprise STEM will perhaps always exert their independence. This centres around how the STEM disciplines can be integrated so that skills, competencies, values, pedagogies, theories, and practical constraints and technologies can all be accounted for in effective lesson planning and design. The ATS took integrated STEM, formative assessment, and digital tools as its starting point to develop a conceptual framework that could guide learning design to help solve real world problems via authentic assessment. The European Commission does not regulate education, and it is accepted that control of public education is always left to individual countries. At the heart of European Union (EU) law is the intention to encourage “cooperation between Member States and, if necessary, by supporting and supplementing their action, while fully respecting the responsibility of the Member States for the content of teaching and the organisation of education systems and their cultural and linguistic diversity” (EUR-Lex, 2008). Within European countries, different standards may apply even at regional levels. Many, but not all, European countries have federal structures. Despite this complexity, the European Commission is keen to develop and enhance critical skills, known as transversal skills, in students—particularly in areas such as STEM, which is one of its key priorities (Costello et al., 2020). The Assessment of Transversal Skills in STEM (ATS STEM) project was developed with these aims in mind, bringing eight European countries (Austria, Belgium, Cyprus, Finland, Ireland, Slovenia, Spain, and Sweden) into this venture (https://www.atsstem.eu).

STEM education has been given high priority by governments and education policy makers worldwide for many years because it is seen as crucial to future global economic prosperity and welfare. More recently, ecological sustainability has become an increasing priority for STEM education. The most important underlying assumption is that countries with dynamic economies tend to be the ones with effective education systems that prioritize STEM education. However, STEM is a contested concept. It is both ill-defined and context-specific, with different driving forces and limitations in different socio-political contexts. Many education systems face profound challenges in helping students understand how to solve real authentic problems using knowledge gained through STEM disciplines.

The Erasmus+ innovative experimentation policy project ATS STEM is relevant to STEL because it is concerned with many of the same issues. It attempts to develop a rich and evidence-informed educational framework to improve educational outcomes in technical subjects. The translation from frameworks or standards to practice is a key challenge in education. For instance, in trying to compare and contrast the work of ATS STEM with that of the STEL standards, we can find that certain terms and concepts map well while others do not. For instance, STEL "benchmarks" can map to "learning outcomes" in our work. The STEL framework is comprehensive and mature. By contrast, although our 36-month project was based on several in-depth reviews of best practices, our framework is necessarily not as comprehensive or broad in scope as the STEL framework. There is a higher level of detail and support that the STEL standards supply through lesson plans and other resources than we did, although we are currently developing a tool to help educators see a bigger database of examples of activities implemented. In the ATS STEM project, we had a relatively limited scope. In addition, we contended with the highly context-dependent nature of varied educational environments, systems, and languages, from sunlit playgrounds in Cyprus to the snows of Sweden. For example, in place of the 142 STEL benchmarks, our framework provides the tools for teachers to develop their own benchmarks (outcomes), acknowledging the complexity of the eight countries' national educational curricula. Our focus was on explaining to teachers how to construct their own learning outcomes aligned with national policies and curricula using feedback based on best practices, in particular, and how to share and evaluate those outcomes via classroom conversations. We will next provide an overview of the ATS STEM theoretical framework that describes its standards.

Development of the ATS STEM Conceptual Framework

A series of five reports were written after a desk-based research phase, to help provide a theoretical base from which the project could proceed.

- Report #1: *STEM Education in Schools: What Can We Learn from Research?* (McLoughlin et al., 2020), which reviewed 79 publications and, in so doing, identified 243 specific STEM skills and competences, which were classified into eight core competences.
- Report #2: *Government Responses to the Challenge of STEM Education: Case Studies from Europe*(Costello et al., 2020), which traced the policy landscape across the eight partner countries and mapped overlapping areas of interest to highlight STEM policy and educational initiatives targeted at specific underrepresented groups and industry collaboration with partnerships across diverse stakeholder groups.
- Report #3: *Digital Formative Assessment of Transversal Skills in STEM: A Review of Underlying Principles and Best Practice* (Reynolds et al., 2020), which addressed two major themes: (1) the key ideas and principles underlying formative assessment theory

and (2) the current state of the art with respect to how STEM digital formative assessment is conceptualised and leveraged to support learning of transversal skills.

- Report #4: *Virtual Learning Environments and Digital Tools for Implementing Formative Assessment of Transversal Skills in STEM* (Szendey et al., 2020; see also Kaya-Capocci et al., 2022), which analysed several frameworks for technology-enhanced learning and then outlined the potential of nine digital architectures to be used for formative assessment.
- Report #5: *Towards the ATS STEM Conceptual Framework* (Butler et al., 2020), which drew on the first four reports and presented an integrated conceptual framework of standards for the assessment of transversal skills in STEM. This became a conceptual tool to help European educators reach a common understanding of what integrated STEM education is and how it can be assessed using digital tools in schools (See Figure 1).

Figure 1. *ATS STEM Standards Theoretical Framework*

Translating Educational Standards

We attempted to enact this theoretical framework with teachers in schools across European countries in the project. The regional and country differences in European education can be vast. Not only are we using an array of different languages but, even after translation to the project working language of English, it was still evident that great differences remain. For example, in Sweden technical drawing is a part of a subject called technology (*teknik*) education. Technical drawing is a subset of this subject that uses pencil and paper and digital tools to convey or communicate technological ideas. In Ireland, technical drawing has historically been a separate subject within the domain of technology education. In Sweden, computer programming is integrated into both technology education and mathematics. This technology education subject *teknik* runs through compulsory schooling (from year 1–9, for 7 –16-year-olds) as a mandatory subject and is even mandatory with its own curriculum in special education schools. Whereas in Ireland "coding" is an optional subject in the junior cycle of secondary school whilst Computer Science has recently been introduced at senior cycle level. These are just two examples, and there are a myriad others within the European school context.

Given the differences in educational systems, the project decided to align the project around learning outcomes that would solve real-world problems. These problems are universal and understandable in any language. Moreover, big problems require integrated approaches. We took the United Nations Sustainable Development Goals as a basis (United Nations, 2015). These 17 global goals provided the project with a tangible basis for framing problems that were comprehensible to everyone and are already in use in many educational systems.

Figure 2. *UN Sustainable Development Goals*

In the project, a structure was developed for lesson plans that would be designed together with teachers. All lesson plans would include two learning cycles and the embedding of digital formative assessment

Illustrative Examples of sTEm Activities Within the ATS STEM Project

Within the STEM disciplines, technology and engineering are two of the most contemporary and rich disciplines to prepare learners for the future. They are defined and enacted differently within different educational contexts but, more importantly, they change rapidly as society changes; equally, they provide historical perspectives. To prepare students with critical skills for the future, technology and engineering education must occupy greater space and play a larger role in school to allow every boy and girl the opportunity to flourish, both for themselves and for society.

Understanding, developing, and supporting this quest is challenging for schools, teachers, and researchers. Developing instruction is key, and bridging educational research and practice gives us greater potential to succeed. The STEL framework has contributed to enlarge the T and the E within STEM by providing a rich model of standards that are theoretically derived and can be practically implemented. In the ATS STEM project the use of digital tools was embedded in all aspects of the project and students used a variety of digital tools such as Minecraft and practices such as design.

To acknowledge the topic of this book we have chosen two examples that particularly emphasize technology and engineering born from the ATS STEM framework, and that feed into and connect with the STEL framework. Focusing into practice from theory and then widening out from practice to theory we can unite around classroom activities using different frameworks. In this way we learn from each other by trying on different lenses according to the two frameworks. We will illustrate some examples of practices in Irish and Swedish schools involved in the pilot research.

Examples from Irish Case Study Research

The following case is drawn from an in-depth report on the field trials of the project that were conducted in Irish schools by a team of researchers comprising Dr Colette Kirwan, Dr Prajakta Girme and Dr Eamon Costello. The research is covered in more detail in Kirwan et al. (2021). Our first case study was situated in a co-educational primary Catholic school of 177 pupils with a largely rural/semi-urban catchment area. The pupils and parents/guardians of the 6th class (final year of school, ages 12-13), together with their teacher, consented to be involved in this research. The case study involved 19 students aged 12-13. For the purposes of this research and of implementing the ATS STEM framework, they selected science, art and history to integrate via STEM. This student project maps closely to STEL 7: Design in Technology and Engineering Education.

Teaching was conducted with these students over two learning cycles . In the first learning cycle, students designed a 2D Sensory Garden and an arch. The Sensory Garden was to be built on the school grounds during the summer of 2021. This task allowed students to contribute their ideas before the landscape designer and builder started the project. It was intended to give students input into a real-world problem and the chance to conceive of themselves as change-makers in their environment.

The teacher used six ATS STEM frame learning design cards to help plan their lesson. These cards break up the ATS STEM conceptual framework into its consistent elements. They draw broadly on visual learning design methods, particularly for allowing teachers to talk about learning design and plan their teaching carefully. The cards identify the core steps outlined as important when designing a STEM task. Figure 3 shows cards titled “Real-World Contexts” as a learning design principle and starting card (“Setting the Context”) that the teacher completed.


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ontexts
This is a STEM learning design principle that connects the subject matter to real-life to make learning more meaningful to students.
All other principles can refer to real-world context when developing integrated STEM tasks.
The use of real-world context is one of the fundamental principles in integrated STEM tasks.
DIGITAL
TOOLS

Figure 3. STEM Learning Design Prompt Cards, Setting the Context Card Filled Out by the Teacher

The cards scaffold teachers to consider the following elements in their lesson planning: Setting the Context, Core STEM competences, Learning Outcomes and Success Criteria, STEM Learning Design Principles, Digital Formative Assessment, and STEM Task Details. The Digital Formative Assessment element of the framework gives teachers guiding prompts for selecting (digital) technologies for assessment. Key principles by which teachers can intentionally use digital tools for teaching are that they are “functional, flexible, practical and above all, useful in ensuring that formative assessment leads to improvements in learning” (Szendey et al., 2020, p.17).

The context for designing a 2D garden was UN Sustainable Development Goal 3 (SDG 3): Good Health and Well-being. This goal was chosen because it addressed the following topics from the Irish geography curriculum at primary school level: “A sense of space,” ”Using pictures, maps and models,” ”Human environments,” and “Natural/built environmental features and people.”

The task of designing the sensory garden focused on two core STEM competences: Problem-solving and Innovation and Creativity. These "competencies" map to STEL "practices." The elements of problem-solving that the students engaged with were gathering information, decision making, and finding solutions.

The elements of innovation and creativity that they engaged in were using their imagination, coming up with new ideas, and physically creating something original. The learning outcomes and success criteria were defined at the outset. The learning outcomes were to research ideas for a sensory garden, measure the area of the garden, and finally design a 2D map of the gardens. The success criteria the teacher would check for were identified as students being able to identify at least three items for the sensory garden and produce a 2D draft plan to scale with the location of sensory items labelled. It should be noted here that there are parallels here with the STEL framework, for example STEL-2L, Create a new product that improves someone's life; STEL-2M, Differentiate between inputs, processes, outputs, and feedback in technological systems; and STEL-2N, Illustrate how systems thinking involves considering relationships between every part, as well as how the system interacts with the environment in which it is used.
The online notice board tool Padlet was used by the teacher during online classes to (1) display learning outcomes, (2) focus students' attention on ideas for the sensory garden, and (3) display student designs during class. The feedback and voting tool Mentimeter was used by the teacher to ask: How will we measure the space for the proposed sensory garden? The teacher had created a video of the proposed site for the sensory garden and shared with students. She described how she mixed asynchronous and synchronous tools to reach students: "Using Mentimeter, students answered it in their own time, because not all students attended the live online daily Zoom classes."

The teacher had intended for students to create 3D plans of the sensory garden using Minecraft. This was not possible after the COVID-19 lockdown, when school buildings were closed and students were remote schooling. It was again planned for Learning Cycle 2 when schools reopened, but was hampered by software configuration difficulties. Learning Cycle 2 became more "outdoor" focused, ensuring students spent more time outdoors during their school day following the COVID lockdown. During the implementation of Learning Cycle 1, the teacher found she needed to give students more direct instruction in the lesson, so she added a task "design an arch for the garden" to the next cycle.

Learning Cycle 2 was concerned with students identifying native Irish trees and creating an eBook of the same. The identification process focused explicitly on bud identification because the activity took place in Spring 2021, when not many trees had leaves. The context for this STEM task was the UN SDG 15: Life on Land. Similar to Learning Cycle 1, the participant teacher completed six ATS STEM learning design cards. Figure 4 depicts the first card, “Setting the Context,” where teachers link their lesson to overarching goals.

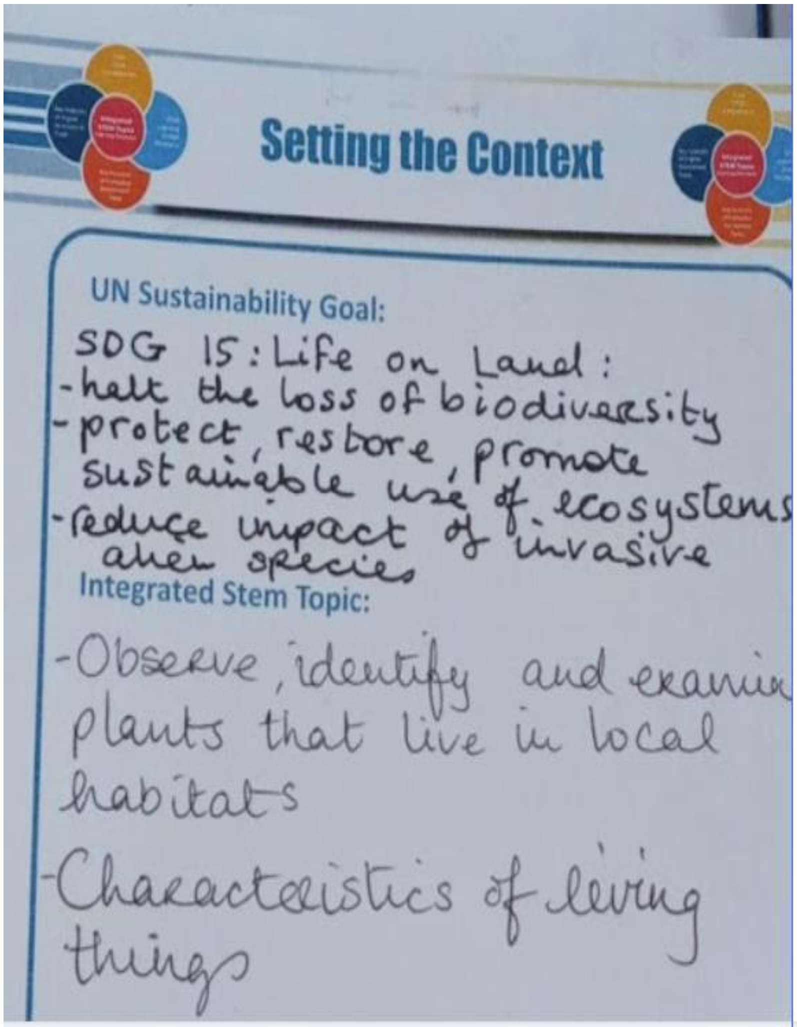

Figure 4. Setting the Context ATS STEM Learning Design Card

Th**e** Life on Land goal integrated the following STEM topics: “Observe, identify and examine plants that live in local habitats” and investigating the “Characteristics of Living Things.” The task of identifying native Irish trees focused on three core STEM competencies: Problem-solving, Collaboration, and Disciplinary competencies. The elements of problem-solving that the students engaged with were gathering information, asking questions, and making decisions. The elements of collaboration concerned students working together to effectively communicate with each other, and to take turns with the use of the iPads. This competence was particularly relevant, as students were just back into school after a three-month lockdown, and as part of COVID restrictions students were placed in class bubbles and pods. The last competence concerned students' use of technology, specifically the iPad. Students created an eBook on native trees, using the iPad and also a self-assessment rubricr. Mentimeter answers were given to tree identification questions and via a booklet quiz.

The learning outcomes were defined as making a tree identification guide, gathering information via iPad/laptop, identifying native Irish trees around the school, working with others, and taking turns. The success criteria were how well children gathered information, asked questions, and made decisions as part of a group; and whether children used computers effectively to take photos and add them to Padlet/Adobe webpage/Book Creator. Students used a variety of digital tools and associated assessment strategies. The Book Creator digital tool was used to create books online. This tool allows the teacher to create a digital library where all students can store their books, thus allowing the teacher to show work in progress from each group to the class and enabling teacher and peer feedback.

Examples from Sweden Case Study Research

The first example from the Swedish Case Study was an activity called "Is it in the Bin?" The context for this activity was students aged 10-12 years old learning in a multilingual school environment. The subjects included in this example are STEM, Swedish, Swedish as a second language, and English.

Targeted skills that were formatively and digitally assessed during the project included communication skills, problem-solving skills, content knowledge, and meta-cognition. Defining a real-world problem related to SDGs, this project took its starting points from the students' perspective and was a good example of how to keep your students' attention in STEM. These 10–12-year olds were very upset at how messy the recycling station near the school was. Two teachers seized the learning opportunity and picked up their students' interest and concern for this real-life problem. They were able to put the students' concern into the context of the UN Sustainable Development Goals and the ATS STEM framework. Sustainable development is emphasised in the Swedish national curriculum and in society, and something the students cared about.

This project particularly focused on SDG 12: Responsible Consumption and Production and was structured in two learning cycles, as the ATS STEM framework suggests.
The first learning cycle particularly focused on concepts and on content, putting it into the context of the real-world problem identified by the students. How to recycle? Where to put what waste and why? What are the different kinds of materials, such as plastics, that can be recycled? There was a lot of focus on vocabulary, both the academic vocabulary and the Swedish language in general, because the majority of the students here have Swedish as their second language. The

multicultural school environment presented in this school deliberately supports learners in the Swedish language through these activities.

The first learning cycle began by finding out students' starting points on what they knew already about recycling. In small groups, students sorted pictures of different items of rubbish into pictures of different recycling bins. The students discussed how to recycle all the items and presented their conclusions to the whole group. Teachers elicited evidence of learning via different means of activities, e.g., playing Memory (Figure 5), and some additional online quizzes. These activities were all formative and done in groups, pairs, and individually. The teacher carefully monitored content and vocabulary and adapted the learning activities to meet students' needs. The teacher also had to find ways to meet learners' needs in terms of content and vocabulary. For example, students faced step-by-step more challenging sorting schemes; for example, eggs in a box could be considered either food waste or cardboard waste.

Figure 5. *Students Learning Concepts and How to Recycle through Play (Photo credits: ATS STEM Team Sweden)*

One of the students' tasks was to build up arguments for why it is important to recycle. They worked in small groups to complete a collaborative exercise of building a timeline showing how long it takes for different materials to degrade (e.g., glass, paper, chewing gum, etc). One of these timelines is depicted in Figure 6. Students discussed which materials took longer times to degrade than they expected, and which materials they didn't previously know how long would take to degrade.

Figure 6. *Timeline for Degradation Time for Different Materials*

Another activity was discussing the differences between living conditions and waste during the Stone Age and the present time. This discussion was based on an illustration of the huge extent of waste that people produce nowadays compared to during the Stone Age, and aimed to open students' eyes to how long certain materials take to break down and "disappear." This discussion also fostered understanding of why it is important to recycle and sort materials. This was a real-world dilemma for the students, and some students had commented in class about littering at the local recycling stations.

The second learning cycle focused on more practical observation and had a more inquiry-based approach in which students made observations of the local recycle station (Figures 7 and 8). Through these observations they were trying to understand the problem and find solutions to solve the problem with the messy recycle station. Students followed what happened at the recycling station every day for one week, documenting by photo what they observed, making annotations of their investigations, and discussing questions raised through this field work. The students themselves identified the need to inform the local community why recycling is important, not only to sort out the local problem with the mess at the recycle station but also to help residents understand the wider picture. They made posters on which they proposed suggestions on how to recycle better and how to avoid making a mess around the recycling stations. These posters were exhibited at the school library. The students were very proud of their work.

On the same topic they also wrote submissions to the local newspaper. By that the teachers did not only teach them about content they also provisioned them with tools on how to influence the local community by democratic means amplifying student voice. Not only by supporting them in their science and technology understanding but also in the language in general and give them tools on how to influence society fostering democratic citizens. The particular focus on digital tools gave a “boost” in confidence among the teachers involved as they previously were not so familiar in using digital tools in their teaching. Together with their students and support by the ATS STEM framework they found ways to include digital tools in their daily teaching where it supported learning. This was done by experimenting in a deliberate way.

Figure 7. *Students O bserving and Documenting Recycle Stations*

Figure 8. Students Analysing the Waste Found in the Recycle Station ([Photo credits: ATS STEM

Students continued to use the ATS STEM transversal skills vocabulary even after the project concluded. Student engagement and interest was high, particularly when engaging with nearby society about the messy recycling station.

Below we select four of the STEL benchmarks and give a short explanation of how each could be mapped to the project described above. The four benchmarks are:

3-5	**4I.** Explain why responsible use of technology requires sustainable management of resources.
9-12	**4Q. Critique whether existing or proposed technologies use resources sustainably.**
3-5	**5D. Determine factors that influence changes in a society's technological systems or infrastructure.**
Pre-K-2	**4D. Select ways to reduce, reuse, and recycle resources in daily life.**

For example, benchmark 4D under STEL 4, Impacts of Technology, indicates that at the PreK-2 level students should be able to "select ways to reduce, reuse, and recycle resources in daily life." Because it provides students with content knowledge, this benchmark may support their understanding of the importance of recycling. A possible continuation of "Is it in the Bin?" is to have a follow-up where students find ways to reuse some of the garbage, they have just learned about how to recycle. Or they could learn more about the recycle chain of material (e.g., aluminium cans that become new cans or PET bottles that may become fleece shirts). The example has touched upon the importance of sustainable management of resources and its complexities, as addressed in benchmark 4I, which states that students should be able to "explain why responsible use of technology requires sustainable management of resources." Importantly, this involves critiquing existing ways of handling resources sustainably, fostering students' understanding of the complexity of this goal. "Is it in the Bin?" allowed students to reflect upon their own ecological footprint compared to their ancestors during the stone age, addressing benchmark 4Q: Critique whether existing or proposed technologies use resources sustainably.

Lasty, giving the "voice" and democratic means to impact society and steer society in a more sustainable direction was something well met in our recycling example. Students became aware that today's ways of handling the situation also may not be best. Therefore, schools must take an active part to foster life-long learning among today's youth to keep people engaged with these issues, as clearly stated in STEL 4L and 4M, which state that in grades 6 to 8 (typically ranging in age from 11-14), students should be able to analyze how the creation and use of technologies consumes renewable and non-renewable resources and creates waste, as well as to devise strategies for reducing, reusing, and recycling waste caused from the creation and use of technology.

Conclusion

Many education systems face profound challenges in helping students understand how to solve authentic problems using knowledge gained through STEM disciplines. The international research and development project described in this chapter may contribute to solving this issue. It has not been easy to facilitate the needs of students and teachers from eight countries; however, it has been easy to make sure every partner's needs have been taken care of. We learned from each other in this project about our own systems and standards by explaining them to others. In a similar way, the STEL standards, even if they cannot be directly applied in another context such as Europe, can be valuable for generating conversations around education's essential elements.

Our project highlighted differences in emphases in the two overarching approaches and also found interesting commonalities. Both frameworks embrace environmental issues though in different ways. The ATS STEM framework orients all of the student work around an SDG goal and it is arguable there is more focus on these development goals of the 2030 agenda. Whether either framework gives greater or lesser environmental emphasis may be a moot point. The bigger question is: Does either framework do enough? The climate and ecological disasters that are unfolding are some of the most urgent issues we can tackle with our students.

Technology is a means for fostering communication skills, not just the traditional technology/engineering communication skills such as technical drawing but, more importantly, educational support for content and subject domain specifics as well as generic and broader academic language. Having an inquiry-based approach to integrated STEM teaching may seem controversial in some contexts. However, this project has contributed to finding ways to raise students' voices and concerns within an inquiry approach. How technology education may support student voice and language is not as prominent in STEL, and how technology may support student engagement for a better world is not as explicit as the route we took in the ATS STEM project due to the enquiry led nature of the projects During peer review of this chapter however an expert in STEL pointed out that STEL is not a curriculum and that we should not compare activity examples with it. Indeed, this reviewer helpfully pointed out that our work may represent examples of how STEL benchmarks can be applied to support student engagement for a better world.

In their seminal paper *Why Minimal Guidance Does Not Work* from 2006, Kirchner et al. critique inquiry-based learning approaches but also do not state they should not be used. Instead, and perhaps more importantly, they amplify the importance of providing students with agency to handle inquiry approaches, which is concurrent with Sjöberg (2019). None of these authors discredit hands-on-activities; instead, quite the opposite in emphasising the importance of guidance and planning. The ATS STEM examples could be seen as a step towards providing students with tools necessary to conduct investigations and tools to suggest how to solve real life problems like the messy recycling station in the vicinity of their school. Students were provisioned with opportunities to learn how to recycle (e.g., which material goes in which container) and also learned about how to write to local media or inform parents, at the same time increasing their academic vocabulary.

Based on the results from the ATS STEM case studies we found that by engaging students in real life problem solving, the students do not just reproduce facts. The choice of the content that comprised their learning in these activities focused on content that could build knowledge (i.e., that afforded students with tools to influence society). The students did not just reproduce existing solutions, they extended the solutions to new and novel contexts based on their own transfer and scaffolding of knowledge and problem-solving. Ultimately it is our contention that this improved their means to be part of and influence their local communities and environments and hopefully, in time, wider society.

We end by pointing out that this project was undertaken during the pandemic. Teachers in schools tackled the pandemic in different ways, but also engaged in this project. We asked some teachers if they wanted to drop the project, and the response we got was that the support they found in the group was a relief amidst all the pain. We are deeply grateful for all their commitment and support and also grateful that the project proved useful to them in human terms beyond our core original research aims.

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