Assessment of Transversal Skills in STEM: From theory to practice in a large scale research project

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Abstract: This paper presents an overview of a large scale research project involving teachers and students across eight European countries and involving eleven partner organizations. The project was focused on helping equip students with key transversal skills and competencies. We used integrated STEM as a site to ground the development of these interdisciplinary ways of thinking, being and doing and digital tools as ways to help teachers deepen and enhance their formative assessment practice. We present here an outline of research conducted to develop a framework for conceptualising integrated STEM skills and their assessment via digital tools. This framework identified a number of core competencies and ways to both design and assess for these skills using digital tools. We also give an account of subsequent professional development with teachers and the piloting of developed teaching methods in schools. The next phase was the conduct of evaluations of our work according to a research methodology which aimed to identify best practices for scalable teaching. Some emergent findings and lessons learned along the way from two countries, Ireland and Sweden, are presented as examples here as we complete the analysis stage of the project. This paper aims to contribute to the conversations around interdisciplinary and integrated STEM skills, how they can be digitally assessed and to give an account of the workings of the associated large scale research project.

Keywords: STEM, Integrated STEM, inservice teacher education, transversal skills

Introduction

Equipping students with key transversal skills has never been more important given the scale of challenges that we can face from Covid to the climate. The Assessment of Transversal Skills (ATS STEM) project is a European project working to inform policy and practice around STEM education through digital assessment of key skills and competencies in schools. This paper outlines the genesis and workings of the project, and some emergent findings as we move into the final evaluation phase of field trials with teachers and students from schools across Europe.

When considering skills and competency developments for students much is often of the skills gaps and how we can develop skills that are future focused or even somehow future-proofed. The question educators continually grapple with is what these skills should be and which technologies, methodologies and sciences they be infused into in an interdisciplinary way. STEM can be seen as a way into this problem as it aims to connect up different disciplines and find links between them. Hence we took STEM as a site of transversal or key skills that interrelate, inform and infuse each other. The concept of STEM remains contested but we can see it as one way to help solve problems and develop creative solutions to real world challenges that do not sit easily into one category or discipline, particularly in a digital world that is rapidly changing.

The project described here was conducted across eight European Union (EU) countries through a partnership of twelve organizational bodies: Dublin City University, H2 Learning & Kildare Education Support Centre from Ireland; Danube University Krems, Austria; Go! Het Gemeenschapsonderwijs, Belgium; Cyprus Pedagogical Institute, Cyprus; University of Tampere, Finland; Haninge Kommun, Sweden; Ministry of Education, Science and Sport and the National Education Institute Slovenia; University of Santiago De Compostela, and Consejería De Educación, Universidad Y Fp (Xunta De Galicia), Spain.

The project, funded by the European Commission under its Erasmus+ programme, aimed to enhance formative digital assessment of students' transversal skills in STEM and address European educational priorities, in this case around digital assessment. The project partnership comprised ministries of education, national and regional education agencies; researchers and pilot schools and has now conducted field trials in schools in Belgium, Cyprus, Finland, Ireland, Slovenia, Spain and Sweden.

Towards Traversal Skills Assessment for STEM: Developing a Conceptual Framework

At the outset a series of literature reviews were conducted in four key areas to inform the project and build a research informed evidence base from which to proceed. The research was undertaken from three research centres in Dublin City University with expertise in STEM Education (www.castel.ie), Digital Learning (www.nidl.ie) and Assessment (www.carpe.ie). These research reviews focused on: Key STEM conceptencies; STEM educational policy; digital formative assessment; and virtual learning environments in which key STEM skills can be developed. A brief outline of these four reports is given below and how we used them to develop a conceptual framework to guide the development of a learning design toolkit for teachers.

The first report - STEM Education in Schools: What Can We Learn from the Research?' (McLoughlin et al., 2020) - comprised a systematic review of literature on STEM education research in schools. In its final analysis it considered 79 publications for inclusion and identified 243 specific STEM skills and competences, which were further classified into eight core competences: Problem-solving, Innovation and creativity, Communication, Critical-thinking, Meta-cognitive skills, Collaboration, Self-regulation, and Disciplinary competences.

The second report - 'Government Responses to the Challenge of STEM Education: Case Studies from Europe' (Costello et al., 2020) sought to trace the policy landscape across the eight partner countries and map overlapping areas of interest . The report also considered other selected relevant STEM education policies both inside and outside of Europe. It highlighted STEM policy and educational initiatives targeted at specific underrepresented groups, a focus of industry collaboration with partnerships but also a lack of maturity in dedicated STEM policies in Europe.

The third report 'Digital Formative Assessment of Transversal Skills in STEM: A Review of Underlying Principles and Best Practice' (Reynolds et al., 2020) addressed considered the key ideas and principles underlying formative assessment theory and how STEM digital formative assessment is leveraged to support learning of transversal skills.

It presented key questions for consideration intended to guide the decision-making process relating to the use of formative assessment. The fourth report - Virtual Learning Environments and Digital Tools for Implementing Formative Assessment of Transversal Skills in STEM' (Szendey et al., 2020) outlined the potential of nine digital architectures to be used for formative assessment.

The capstone element of this project phase involved the development of a theoretical framework where the research team got together and attempted to combine the distilled findings of the reports into one conceptual whole. We intended to develop a framework or mapping which we could use to have conversations with teachers and teacher educators about complex ideas of STEM education and its practical design. We published a report - 'Towards the ATS STEM Conceptual Framework' (Butler et al., 2020) that presented an integrated conceptual framework for the assessment of transversal skills in STEM. The framework helped us arrive at an understanding of what integrated STEM education could be and how it can be assessed using digital tools in schools. However, we also knew that this understanding was provisional and that the ultimate test of our learning design would be its translation into practice by teachers. Figure 1 below shows a high level visual mapping of the framework which comprises 29 components, organized in three levels. STEM integrated topics (which may take the form of learning outcomes or objectives) are the central component. Below this we include the four areas of Core STEM competences, STEM Learning Design Principles, Key features of formative assessment and lastly key features of digital learning environments. Beneath these levels are the leaf nodes which comprise more concretised elements.

Figure 1: Expanded ATS STEM Conceptual Framework

Visually we created versions of the framework that allow teachers and learning design teams to focus on particular aspects. Educators could for example pick the node "Real Word Contexts". They can trace this concept through the research literature where it is posited that integrative learning and curriculum theories that connect subject matter to real-life to make it more meaningful to students (Beane, 1997). Intuitively we may feel that instead of being taught in a vacuum, mathematics and science should be brought to life through students' solving a real problem and this notion is indeed borne out by much research in STEM (e.g. Blackley & Howell 2019; Bybee, 2013; Kelley & Knowles, 2016; 2019; Moore et al., 2016;).

Finally, it should be noted that this framework is conceptual and non-prescriptive. It can be used as a basis for the development of curricula and learning activities and that the described elements and competences. As a framework of concepts that sometimes overlap or interrate it requires engagement from users "can help in exploring its implementation and be contemplated as the embryo of a continuous discussion with teachers and educational policymakers." (Sala et al., 2020).

Teacher Professional Development and Mentoring

The next phase of the project involved the development of teacher training tools and materials based on the conceptual framework to help teachers plan lessons that included digital assessment of key STEM skills. Teachers were supported by mentors in each country, who guided them to design and implement the integrated STEM projects in the pilot schools. This workpackage was led by a research and learning design team from Tampere University. The mentors were provided with a guidebook, including essential information about the ATS STEM framework, and activities the mentors could use in face-to-face and/or online workshops to support the teachers' professional development. In addition, teachers were provided with an online platform with similar content, including printable worksheets for designing the implementations. A series of expert webinars were also held with several of the framework developers.

The workflow of using the framework involved firstly the design of learning cycle one: defining learning intentions including targeted transversal competencies and subject-specific learning objectives, success criteria for targeted transversal competencies, formative assessment strategies using digital tools. Secondly an implementation schedule was developed for cycle one. Next teachers reflected by asking "What is my understanding of the student's competencies targeted during learning cycle one? How well did the digital assessment tools work in order to assess the targeted competencies? How would I better support the development of targeted competencies in learning cycle two?" Finally cycle two was designed and implemented with the same students. This resulted in ATS STEM framework lessons being developed and implemented in 88 schools.

Evaluation Methodology

Drawing on the project aims and the conceptual framework four research questions were formulated:

- How could digital assessment practices support the development of STEM skills?
- What are the challenges of using digital assessment strategies in STEM learning?
- Why apply digital assessment in the development of STEM projects?
- What and how does it contribute to STEM teaching and learning processes?

To answer these questions a mixed-methods approach was developed that used quantitative and qualitative research methods. Tools were designed to collect a diverse range of data to provide a rich picture of the students' experiences and outcomes. In total four separate data collection methods and associated tools were developed:

1. Pre and post test questionnaires on students' perception of the development of the eight core ATS STEM competences.
2. Observation sheets for classroom analysis of the interaction, communication, collaboration and reflection dynamics generated by the digital tools used by teachers.
3. Artifact analysis sheets to appraise student work including such as reflections, videos, podcasts, photographs of drawings, screenshots from digital tools, and teachers' feedback on these tasks.
4. Interviews with teachers, students and mentors to allow them to reflect on the process and share their perceptions of how student skills evolved over the course of the project.

Implementation and Research Challenges

The complexities of conducting large scale research projects across multiple countries are daunting. The project team held regular series of online meetings aligned with specific project work packages and workstreams. These were co-ordinated by monthly partners meetings which involved sometimes over thirty participants. Overall project management was provided by industry partner H2 Learning Ltd, an Irish company with expertise in the development and management of complex educational innovation and development projects. In addition a team in the University of

Danube Krems conducted ongoing quality evaluation of the project and concluded risk reporting and planning.

At the macro level, the country leads were also in dialogue with policy makers, as a key aim of the European Commision (the project funders) was that our work should inform policy directly and try to promote lessons learned in systemic and sustainable ways. Several of the project members worked in organizations that were part of educational government sponsored agencies providing a natural link at the policy level.

At the country level, individual challenges presented themselves around the highly complicated nature of working with children in schools. Although the Spanish research team had secured ethical approval for the overall research, both Irish and Swedish research teams also had local research requirements. In this case of Ireland the research ethical approval document itself ran to over 60 pages. The changing demographic makeup of European countries and the increasingly rich diversity of its citizenry was reflected in the Swedish case. The pilot schools in the municipality of Haninge are fortunate to have students from all over the world, and a number of families who have recently immigrated to Sweden. STEM education has a strong policy focus at European and national levels on widening opportunities for under-represented groups (Costello et al., 2020). Swedish researchers hence adapted their research consent protocols to be more inclusive. Given the mixed backgrounds of the parents of the school children in some of their pilot schools, researchers worked with schools to develop multilingual consent forms for parents (for several languages including Polish, Spanish and Arabic). This inclusive approach followed one of project operating principles of engaging with all research participants as partners and in building relationships based at mutual benefit and understanding.

The main challenge of this research was of course the pandemic that descended in its midst and just as the teacher mentor development programme was happening. Huge challenges presented themselves to the researchers as the nature of teaching changed in many schools and school openings were highly unpredictable. As schools reopened they did so firstly in remote modes with students studying from home. Although this threw the teachers lesson planning into uncertainty it also highlighted the teachers great creativity and determination to continue teaching. Much of the student work conducted centered around topics related to the pandemic itself, such as well being and exercise in a Slovenian school, or an award winning project on Covid 19 itself conducted by students in Galicia Spain. This maps back strongly to one of the project's learning design goals about real world assessment (McLoughlin et al., 2020) and helping students to develop ideas of their own agency through education and their ability to impact on their environment. A Cypriot school for example developed plans for developing their school yard as an integrated STEM project that included writing a letter of permission to their school board. Likewise a Swedish school redesigned an area close to their school with a focus on sustainable material and transport of materials whilst in Slovenia children worked to protect the environment for Beavers in a local stream.

Many of the projects we mentioned above involved outdoor activities. In Sweden students photographed recycling materials as part of their study using digital devices to gather data for later analysis. This gathering and analyzing real data particularly using digital tools is key digital competence. The students followed what happened at the recycling station everyday for one week, documenting, investigating, and discussing.

Unlike Scandinavian countries in Northern Europe, there is less of a tradition of outdoor learning in Ireland although this is changing such as via movement towards forest schools (Harris, 2021) and there is a venerable tradition of school gardens (Austin, 2021). One of our rural pilot schools in Ireland undertook a project on designing and developing a sensory garden. This outdoor student project, for students and teachers who had been through lockdown, became a rejuvenating activity. Students used pen and paper to gather information and data from their environment on native trees and their characteristics to help inform their design according to sustainable development goals. The name of the school Coill Dubh means Black Wood in the Irish language and students incorporated hurling sticks (which are similar to hockey sticks) made from local ash trees in their design for an arch for their school garden. Students drew up plans for the garden using geometry and math skills. Students used the digital tools (Blooket and Mentimeter) to give feedback to each other on digital books they had created of their designs and drawings.

The teacher described how she shared success criteria for set tasks with students across learning cycles. She described how she iterated her lesson plans to adapt them to students' needs, narrowing and becoming more specific with her criteria, to scaffold the children and give more clarity as to exactly what was required:

"... it wasn't really 'til they started that I realise what I wanted you know to be more specific and that's exactly what I wanted. So, little kind of diagram, a little description of it, to help them realise and then a photo, they'll eventually put the photo in there of the ash tree that they found too." (Teacher 1).

The fact that much of this learning was happening outdoors was critical to allowing the researcher access to the Irish school to conduct in-person observations of student learning. It helped overcome ethical dilemmas that the research team faced about potential covid transmissions. There are always considerations for research teams in building relationships with participants such that they do not harm or interfere but these took on very new salience during the pandemic. The mentors and researchers from across the project had to constantly consider and reflect in their interactions so as to carefully conduct their work with overburdened and stressed teachers. We attempted to strike a balance here and work in partnership with teachers and schools with the simple guiding principle of: How can we help teachers? As our emergent findings indicate, teachers greatly valued being part of the wider research project itself. It provided a wider sense of purpose, value and connection to their work. To develop this sense of community further we created a series of webinars where teachers from across Europe presented to each other online about their research projects. These webinars, led by members of the research project from the Slovenian Ministry of Education, Science and Sport, proved highly valuable and an incidental form of CPD for the teachers beyond the formal limits of their mentoring as set out in the project plan.

Emergent Findings

Analysis of the project results is currently ongoing and a detailed discussion of them is beyond the scope of this paper. The project encountered challenges in the translation of several concepts from the research literature into language that students are familiar with. In addition, working with students at different levels of education and in countries with different primary languages provided many challenges to transferability and generalisation of findings at a granular level. More work needs to be on development of validation of research instruments for use in multilingual settings. However, the early findings also point to concepts that appear to be more well understood than others. Communication and critical thinking skills for example are competences that are coming through as potentially having been enhanced in the pilot schools whereas asking students via questionnaires to self-evaluate certain concepts such as meta-cognitive skills appears problematic. In part the challenge is in trying to develop shared understanding between researchers and participants about key concepts.

One emergent positive qualitative result however, has been a notable increase in what can be termed teacher and students assessment and feedback literacies (Carless and Winstone, 2020). The strong emphasis on promoting effective actionable feedback in skillful ways by teachers to students has led to the promotion of cultures of feedback, where for example students are more used to the peer and self assessment and experience feedback as dialogue. Teachers have used such cultures of feedback to help for example orient their teaching towards collaboration and in this way modulate competitive instincts. It is only through collaboration that any genuine change can be made in our environments which is a deep educational objective.

Conclusion

This paper presented an overview of a large scale research project working with multiple stakeholders across several sites of activity in different countries. We described the use of our theoretical or conceptual frames, translation to training and development materials and gave accounts of conceptual and practical challenges we encountered. Although the analysis of our results is ongoing and there are interesting emergent findings, we acknowledge that teaching is highly adaptive, creative activity that happens in supported systems and environments. Drawing generalizable conclusions is always problematic given the contextual nature of the activities; however we contribute here an example of using and adapting a framework in a large scale research project as a way to have pedagogical design and implementation conversations. The project involved continuous discussions with teachers, researchers, and educational policy makers about digital assessment of rich integrated STEM activities for cultivation of key life skills for children.

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References

Austin, S. (2021). The school garden in the primary school: meeting the challenges and reaping the benefits. Education 3-13, 1-15.

Bartholomew, S. R., Ruesch, E. Y., Hartell, E., & Strimel, G. J. (2020). Identifying design values across countries through adaptive comparative judgment. International Journal of Technology & Design Education, 30(2).

Beane, J. A. (1997). Curriculum integration: Designing the core of democratic education. NY: Teachers College Press.

Blackley, S., & Howell, J. (2019). The Next Chapter in the STEM Education Narrative: Using Robotics to Support Programming and Coding. Australian Journal of Teacher Education, 44(4), 51-64. doi: 10.14221/ajte.2018v44n4.4.

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. Arlington, Virginia: NSTA press.

Butler., D., McLoughlin E., O'Leary, M., Kaya, S., Brown, M. & Costello, E. (2020). Towards the ATS STEM Conceptual Framework. ATS STEM Report #5. Dublin: Dublin City University. http://dx.doi.org/10.5281/zenodo.3673559

Carless, D., & Winstone, N. (2020). Teacher feedback literacy and its interplay with student feedback literacy. Teaching in Higher Education, 1-14.

Costello, E., Girme, P., McKnight, M., Brown, M., McLoughlin, E., & Kaya, S. (2020). Government Responses to the Challenge of STEM Education: Case Studies from Europe. ATS STEM Report #2. Dublin: Dublin City University. http://dx.doi.org/10.5281/zenodo.3673600

Harris, F. (2021). Developing a relationship with nature and place: the potential role of forest school. Environmental Education Research, 1-15.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11). 1-11. doi: 10.1186/s40594-016-0046-z.

Moore, T. J., Johnson, C. C., Peters-Burton, E. E., & Guzey, S. S. (2016). The need for a STEM road map. In STEM road map (pp. 3–12). NY: Routledge.

McLoughlin E., Butler., D., Kaya, S. and Costello, E. (2020). STEM Education in Schools: What Can We Learn from the Research? ATS STEM Report #1. Ireland: Dublin City University. doi:10.5281/zenodo.3673728

Reynolds, K., O'Leary, M., Brown, M. & Costello, E. (2020). Digital Formative Assessment of Transversal Skills in STEM: A Review of Underlying Principles and Best Practice. ATS STEM Report #3. Dublin: Dublin City University. http://dx.doi.org/10.5281/zenodo.3673365

Sala, A., Punie, Y., Garkov, V. and Cabrera Giraldez, M., (2020) LifeComp: The European Framework for Personal, Social and Learning to Learn Key Competence, EUR 30246 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19418-7 (online),978-92-76-19417-0 (print), doi:10.2760/302967 (online),10.2760/922681 (print), JRC120911.

Szendey, O., O'Leary, M., Scully, C., Brown, M., & Costello, E. (2020). Virtual Learning Environments and Digital Tools for Implementing Formative Assessment of Transversal Skills in STEM. ATS STEM Report #4. Dublin: Dublin City University. http://dx.doi.org/10.5281/zenodo.3674786