2018 HAWAII UNIVERSITY INTERNATIONAL CONFERENCES
STEAM - SCIENCE, TECHNOLOGY & ENGINEERING, ARTS, MATHEMATICS & EDUCATION
JUNE 6 - 8, 2018 PRINCE WAIKIKI, HONOLULU, HAWAII

INTEGRATING STEM INTO THE CURRICULUM: DIMENSIONAL MODELS

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Integrating STEM into the Curriculum: Dimensional Models

Synopsis:

This paper describes a new model of STEM curriculum integration where various combinations of schooling levels and curricular modal integration. Several examples of STEM curriculum integration from around the world are presented characterizing distinct educational scenarios for each type of STEM integration within this model. In presenting these case studies this paper re-conceptualizes the role of STEM in teaching and learning and provides recommendations for future endeavors.

Integrating STEM into the Curriculum: Dimensional Models

Abstract

This paper first provides an analysis of how a selection of schools across the globe (n=31) are integrating STEM curriculum in their contexts. It considers various combinations of schooling levels and modes of curriculum integration. A number of examples of schools' STEM curriculum implementation with related pedagogies are then provided. These are sorted into various modes of integration in order to describe the pedagogical practices associated with each type of STEM integration within their models. Finally, this paper re-conceptualises the role of STEM in teaching and learning and concludes by suggesting exemplary practices of authentic STEM pedagogy.

STEM Modes of Integration

This paper presents a description of various case studies of educational institutions around the world that have implemented STEM practices. In general, the integration of STEM education into the school curriculum has been led by approaches based on the various demands by schooling levels. These are analysed into whether the integration is vertical or horizontal (ACARA, 2015; Becker & Park, 2011; National Research Council, 2012; Sanders 2012). These types of modality are described below.

A vertical integration modality refers to an approach where the STEM pedagogy is taught in a non-cross-disciplinary fashion, or that it is taught separately from an on-going classroom program such as in the form of after school or lunch clubs, competitions or one-off STEM based lessons. This can also be referred to as a 'silo' approach in that the curriculum is compartmentalised. In some instances, authentically integrated STEM learning may be occurring in only one classroom, headed by a STEM focused teacher; or only across one grade group. In schools that have vertical integration, STEM pedagogy may be recognised as important, but may not implement a whole-school, authentically integrated STEM approach.

Alternatively, a horizontal integration modality identifies schools that are implementing STEM pedagogy as a cross-disciplinary, whole-school approach. STEM implementation in schools can thus be identified as belonging to one of the following types of integration:

- Quadrant 1: (Vertical Integration / Upper schooling)
- Quadrant 2: (Vertical Integration / Lower schooling)
- Quadrant 3: (Horizontal Integration / Lower schooling)
- Quadrant 4: (Horizontal Integration / Upper Schooling)

These four quadrants are shown in Figure 1:

	Lower Schooling	**Upper Schooling**	
Vertical Integration	II Vertical Integration / Lower schooling	I Vertical Integration / Upper schooling	**Vertical Integration**
Horizontal Integration	III Horizontal Integration / Lower schooling	IV Horizontal Integration / Upper Schooling	**Horizontal Integration**
	Lower Schooling	**Upper Schooling**	

Figure 1. A STEM Model of Curriculum Integration

After providing a number of example schools, this document will then provide a summary of the key points for pedagogical consideration according to both Horizontal and Vertical Integration. The document will then present suggestions for the key elements to authentic STEM pedagogical implementation. The report will close with a short description of why STEM is considered to have strong educational value in today's educational systems.

The following schools provided a background of the various ways that education systems are approaching the teaching of STEM. These schools were selected through searches in the literature and in the Internet based on their model of STEM integration (Table 1).

Table 1: Stem Case Studies of STEM Curriculum Integration

Model of STEM Integration		Examples
Vertical Integration	Upper Schooling	Northland Preparatory Academy located in Arizona, USA. St Hilda's school Gold Coast, Australia
	Lower Schooling	Hannan's Road Public School, South-Western Sydney, Australia
Horizontal Integration	Upper Schooling	Preston STEM Middle School is located in Colorado, USA. Manor New Technology High Schools International Grammar School (IGS) higher and lower. Math Engineering Technology Science MC^2 STEM High Schools The Skinner School (Academy) Stewart Middle Magnet School Chesapeake STEM Academy Australian Science and Mathematics School in South Australia
	Lower Schooling	The School of Engineering Arts (SEA) Chesapeake Maths and IT Academy (CMIT) Richfield STEM School (R-SYEM) Elementary Frobel Robel Little Scientist Early Childhood Centers Drew Charter School Elementary Academy

Table 2 presents, from the cases described above, a summary of the key pedagogical practices that were occurring in each mode of STEM integration. These can be viewed as significant points of consideration for implementing STEM pedagogy in a vertical and horizontal approach, respectively:

Table 2. Key Points for STEM Models of Curriculum Integration

Vertical Integration / Lower Schooling	Vertical Integration /Upper Schooling
● Inquiry-based pedagogy ● Learning show-case events with STEM focus or inspiration ● Emphasis on creativity and play ● Students collaborate and co-construct ● Links to specific subject areas in the school curriculum ● PBL ● STEM learning limited to specific year groups or individual classes	● Inquiry-based pedagogy ● Partnerships with community and international STEM-related organisations and professionals ● Students involved in real-world projects ● STEM conferences ● Options for students to undertake tertiary STEM related courses ● STEM learning limited to specific year groups or individual classes
Horizontal Integration / Lower Schooling	**Horizontal Integration / Upper Schooling**
● Inquiry-based pedagogy ● Maker spaces ● After-school STEM clubs ● Genius Hour ● Cross-curricular pedagogy ● Authentic real-world links ● Promotion of sustainability and ethical responsibility ● Technology-centred lessons ● Recognition of the importance of play, curiosity, investigation ● Recognition of the importance of engaging young people in STEM	● Project-based learning (PBL) ● 21st century learning spaces- modular furniture, open-learning centres, spaces for group and individual work, high contact with 21st century technology ● connections to community ● connections to STEM organisations and professionals ● connections to Universities ● Quality training for teachers ● Teachers plan co-operatively ● Cross-curricular learning ● BYOD ● High expectations for students to achieve ● Authentic real-world links ● Opportunities for students to gain traineeships and internships outside of school ● Promotion of sustainability and ethical responsibility ● Fab Lab ● Capstone projects ● Tech centred learning

A cross-case analysis of several schools across the globe (n=31), was undertaken by the lead author. That analysis allowed for the consolidation of participating school's evaluation of advantages and disadvantages of their strategies. This paper therefore argues that the key pedagogical practices, outlined from all quadrants, can be combined into a new model of STEM education that places emphasis on the central areas of authentic STEM pedagogy as outlined below.

Key Elements of Authentic STEM Pedagogy

Tables 1 and 2 presented above offer a snapshot of the key analytical points in the implementation of STEM for cross-case consideration. The tables include points that occur frequently at the sites included in this evaluation, or that are ideas of innovative STEM pedagogy. By scrutinising this summary, the following six principles have been isolated as important elements of exemplary STEM pedagogy. These are:

- authenticity;
- project based learning;
- interdisciplinary learning;
- real-world links;
- flexible modern learning environments; and
- inventiveness / making culture.

The operation of quality STEM pedagogy in educational environments would include all, or a large majority, of the principles presented above. These principles encapsulate the core elements of how STEM might be approached in an authentic, practical sense in classroom environments. The pedagogical elements on this list move away from a shallow adoption of STEM in classrooms, where it might be treated as a type of response to STEM as a fleeting 'catchphrase' in education (Handal, 2015). These key elements will now be described in more detail.

Authenticity

The authentic implementation of STEM pedagogy includes the design of learning programs around an authentic problem, theme, or topic; in which students can employ their knowledge and/or skills in science, technology, engineering and/or mathematics; often to design and create artefacts through a process of collaborative problem solving. Following Vos (2015, authentic STEM education would ideally include to a high standard the other key elements described in this list.

Project-based learning (PBL)

PBL is a learning approach that enables students to work for an extended period of time to research and discover solutions to a central problem. The approach is student-centred, hands-on and requires students to actively co-construct knowledge to find solutions to a challenge. The PBL approach is complementary to learning through STEM because it can mirror 21st century working environments and also generate deeper understandings about the real-world application of STEM skills and knowledge (Hajkowicz, Reeson, Rudd, Bratanova, Hodgers, Mason & Boughen, 2016; National Research Council, 2011).

Interdisciplinary learning

An important aspect of STEM learning is that it encompasses more than the sum of its singular academic parts in Science, Technology, Engineering and Mathematics. Interdisciplinary approaches to STEM draw meaningful connections between curriculum areas and allow students to hone problem-solving, communication, collaboration and creative skills; as well as competencies in each of the individual disciplines (Becker & Park, 2011; Capraro & Jones, 2013). Exemplary STEM programs will authentically integrate curriculum areas outside STEM, including literacy, Social Sciences, History and the Arts (Capraro & Jones, 2013).

Real-world links

Purposeful and engaging STEM learning includes opportunities for students to build understandings of the real-world significance and utility of STEM outside the classroom. In quality STEM programs, students can make connections to the outside world, comprehend how their skills can be applied and realise the importance of their learning (BOSTES, 2015; Education Council, 2015). This can also be augmented by schools having links to local and/or global STEM organisations and professionals, for students to interact meaningfully with STEM in practice in the outside world. Students ask critical questions about the world around them, examine how they can contribute to local and global solutions and understand their social responsibilities (Handal, 2015).

Flexible, modern learning spaces

Learning environments that allow flexibility for different teaching and learning approaches, and that complement constructivist and inquiry-based pedagogy, are best suited to STEM education (Montoya & Hernández, 2016). Spaces might include a variety of choice for different styles of learning such as grouped tables for teamwork, individual desks for quiet personal work and empty floor space. Such environments might include modular furniture that can be adapted easily to suit any task. As highlighted by Capraro and Jones (2013), in quality STEM learning environments, students would have access to tools to facilitate their learning, from Lego blocks to iPads, whiteboards to laptops, and circuits to Wi-Fi, for example.

Inventiveness / making culture

To facilitate authentic STEM pedagogy, students need the time and space for planning, design and construction to enact the creative practical expression of their ideas. High quality STEM learning environments allow students to see themselves as being able to actively contribute to the world around them by creatively constructing ideas and products that answer critical local and global problems (Martinez & Stager, 2013).

Conclusions

The discussion above has elaborated the core elements that depict authentic STEM pedagogy for classroom learning. These elements not only illustrate important considerations for STEM pedagogy but are also critical building blocks for any quality learning environment. STEM is presented here as having high educational value for its potential to:

- provide anchors for a highly changing world and unpredictable future;
- allow students to gain meaningful socio-cultural-economic awareness; and
- increase student engagement by facilitating deep and highly effective learning opportunities for students.

This paper has presented an outline of various case studies of STEM pedagogy in different educational contexts around the world. In doing so, it has highlighted key points for consideration in terms of the way that STEM might be employed authentically in schools. It has offered suggestions of the key elements for meaningful STEM integration and highlighted why STEM is considered to be of strong educational value.

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