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STEM education and the spiral curriculum: Reinventing the wheel as a work in progress

Solina Quinton, University of Waterloo

Solina Quinton is an environmental engineering graduate from the University of Waterloo with a passion for education. Her experience in the field of engineering education began during her time in Australia working on The SILO Project, an integrative STEM education resource for primary students. Solina has continued this work to focus on the Ontario curriculum, and her goal is to continue to connect with and further inspire students' interest in STEM learning.

Dr. Rania Al-Hammoud P.Eng., MpowerU Training & Consultancy Inc.

Rania Al-Hammoud is an associate professor teaching stream and the current associate chair of undergraduate studies at the civil & environmental engineering department at university of waterloo. Dr. Al-Hammoud has a civil engineering background with research focusing on materials and the rehabilitation of reinforced concrete structures. She also has passion for engineering education and has published widely in this area. She cares about the success and well-being of her students, thus always being creative with the teaching methods in the classroom. Outside the classroom, she is an active person, with the following hobbies: hiking, biking and dancing.

Dr. Brendan Jacobs, The University of New England

Brendan Jacobs is an Associate Professor and Head of Department (STEM Education) at the University of New England, Australia. His research interests include STEM education, explanatory animation creation, conceptual consolidation theory, and provisional multimodal research.

Sogra Fathima, University of Waterloo

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Abstract

This paper reports on a lesson sequence based on circles and rotation as a theme to build on prior knowledge and introduce more advanced concepts in primary school settings. Initial findings suggest that the affordances of circles and rotation can provide a logical and familiar context to introduce more complex STEM concepts such as ratios, exponents and even nanotechnology. The evolving lesson sequences are part of a work in progress in a longitudinal STEM integration project where STEM resources are published in draft form on an open-access website [1]. Our research is based on Bruner's spiral curriculum [2] which provides a rationale for the early introduction of STEM concepts to prepare our students for the increasingly technological world in which we live. As the lesson sequences in this paper have been successfully implemented in elementary schools in Australia and Texas, the researchers intend to continue trialing the content into Canadian classrooms and beyond. The mechanism for this is through collaboration with teachers who use the open-access STEM content and then choose to provide feedback based on their professional judgment.

Keywords: Prior knowledge, scaffolding, spiral curriculum, STEM.

Introduction

The phrase 'Reinventing the wheel' is generally used as a negative idiom about the futility of undertaking a redundant task. However, the title of this article is not to suggest a new wheel, but to report on a research project which uses the properties of circles and rotation as a scaffold for STEM education. We propose that the attributes of circles can present rich opportunities to extend children's STEM knowledge into topics which they would not normally encounter until middle school, such as ratios and exponents.

Since Bruner first proposed his spiral curriculum in 1960, the practice of revisiting topics with increasing complexity and depth became widely influential across all stages of education including the early years [3]. The central idea which will be explored in this paper is Bruner's hypothesis that "any subject can be taught effectively in some intellectually honest form to any child at any stage of development" [2]. This paper introduces a range of activities from The SILO Project, which is a longitudinal STEM integration study which commenced in Australia in 2020 [4]. SILO is a recursive acronym based on Scientifically Integrated Learning Outcomes. It is recursive by referring back to itself as the overall emphasis is to find the intrinsic connections across the STEM subdisciplines, and to move away from teaching in silos where students often fail to see how their learning connects to other areas. The SILO Project was created as an open-access catalyst for change to integrate STEM education in primary schools while seeking to articulate and document authentic connections across the disciplines of Science, Technology, Engineering and Mathematics. The effectiveness of the implementation of The SILO Project, and the role that Bruner's spiral curriculum plays in students' understanding of the early introduction of complex topics has an impact on increasing student's confidence and engagement in the classroom [5].

Research methodology

The research methodology used in The SILO Project is Provisional Multimodal Research (PMR). PMR was developed to document multimodal artefact creation and provide a logistical solution to version control [6]. PMR requires the researcher to archive each version of an artefact and also provide a rationale for any changes which are made. These two elements in tandem "extends the notion of digital scholarship from a methodological choice to an epistemological stance" [7]. PMR is best suited to longitudinal qualitative studies where incremental improvement is likely to be ongoing.

The overarching goal of The SILO Project is to incorporate appropriate STEM learning sequences into the 28 STEM units on the SILO website [1]. There are 28 units as the draft content provides ideas for four school terms across the seven years from K-6. If new or emergent ideas do not fit logically within the current framework, the framework is modified accordingly.

Data analysis

The participants in the project are teachers and researchers, not the students. Accordingly, data analysis involves a critique of lessons within the project. This can occur during classroom sessions or at any time whenever unit development is undertaken. Modifications to the lessons are usually made by the chief investigator who is also the webmaster for the website. Whether inside or outside the classroom, data analysis is conducted using professional judgment to make and document improvements. These practices result in web content either being current or archived. For example, whenever the circles.html webpage was revised, the html file was copied and then renamed with the current date. The file with the current date is then archived. As the revised file retains the same name, the updated file is simply uploaded to the SILO website to overwrite the old file. Users of the website are only ever exposed to current content as archived content is kept offline as a form of version control in what is called “referential chronology” [6].

Although feedback is normally provided by teachers and researchers who are actively participating in the project, constructive feedback can be provided via email by anyone who uses the open-access site. Data collection and analysis in PMR is essentially a process of validation and incremental improvement. STEM units are embodied in separate webpages which have more content than can be covered in a single lesson. A typical session involves trialing activities and then implementing any changes which were deemed necessary as an iterative process. Building flexibility into units is considered necessary as timing can vary from one classroom to another for a myriad of reasons, including the length of a given session. As each unit is embodied on a single HTML page, teachers can scroll through the content to suit the needs of their students.

There were numerous examples of STEM content involving circles and rotation throughout the SILO website before the creation of a designated circles unit. However, some of this content was compiled and edited as a themed collection for the purpose of trialing this unit in schools. To date there have been 27 separate iterations of the ‘Circles and rotation’ unit, and each iteration had involved improving the clarity, flow and suitability of materials. The most significant changes will be recounted in the same order in which they currently appear on the *Circles and rotation* page [8].

Preliminary Data and Results

The following excerpts from the circles and rotation unit have been trialed in Australia and North America in both public and private schools. The unit was well received in Houston, Texas during a one-week intensive in the Lower School of a private K-12 school in December 2025, but it has yet to be trialed in Canada. The extension of this work into Ontario will simply require classroom teachers and researchers to trial the unit and then provide feedback to the chief investigator. A baseline comparison of existing content is not required. This is because any changes which result from trails in Ontario will be implemented directly in the *Circles and rotation* page [8] and all pages in the SILO website [1] are the same throughout the world. Teachers involved in the Houston trial further assisted in the development of the unit in real time as changes were made each day, often during short breaks between classes as PMR can facilitate rapid prototyping. The unit evolved around the related concepts depicted in Fig. 1. It was originally envisioned that individual concept maps would be constructed by each student over multiple sessions as a chronology of learning, however, during classroom trials it became apparent that the most useful approach was to display the following concept map early on in the sequence to promote initial classroom discussions and brainstorming.

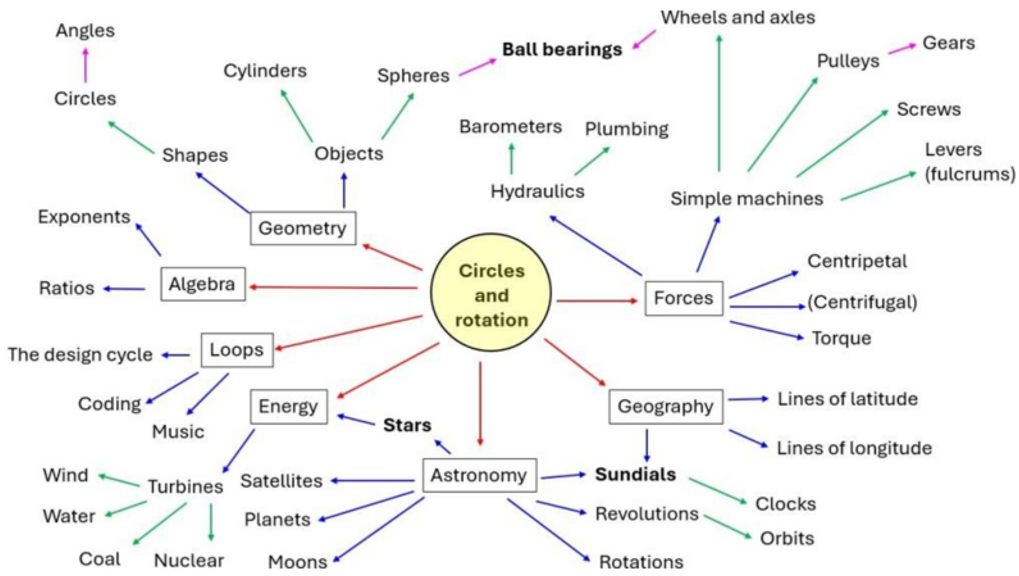

Fig. 1. *Circles and Rotation as a Scaffold for STEM Education. Adapted from [8].*

Although there are some connections in Fig. 1 which might be considered to be outside of a STEM curriculum such as music loops (STEAM) and geography, there are also instances of words which occur across multiple branches. Two examples of this are ball bearings and sundials.

Exploring mechanisms and linkages

The following activity is also included in SILO 2.2 'Construction zone' where students create simple mechanisms using fixed and floating pivots to change the direction of movement. This engineering activity provides an opportunity to introduce the design cycle. Using the word 'cycle' rather than 'process' is a good starting point as cycle implies multiple iterations of design improvements. There are several variations of the design cycle, but the one adopted here is TMI (Think, Make, Improve) first proposed by Martinez and Stager in 2013 [9]. Children are unlikely to forget the three steps in TMI in contrast to existing design models which "may be too wordy or abstract for young learners" [10].

When introducing the concept of fixed and floating pins, some familiar examples are elbows and knees for floating pivots and boom gates and door hinges for fixed pivots. However, the creature with arms and legs in Fig. 4 has fixed pins in the position of the elbows and knees. This is because the arms and legs remain straight as they rotate from the shoulders and hips.

Students are generally very creative with this open-ended engineering task as they can demonstrate a wide range of applications for linkages in toys including robots, monsters and even food objects such as tacos and burgers. The only critical design specification is that rotational movement must be involved. Fig. 2 shows two options for making linkages using cardstock, split pins, straws and tape.

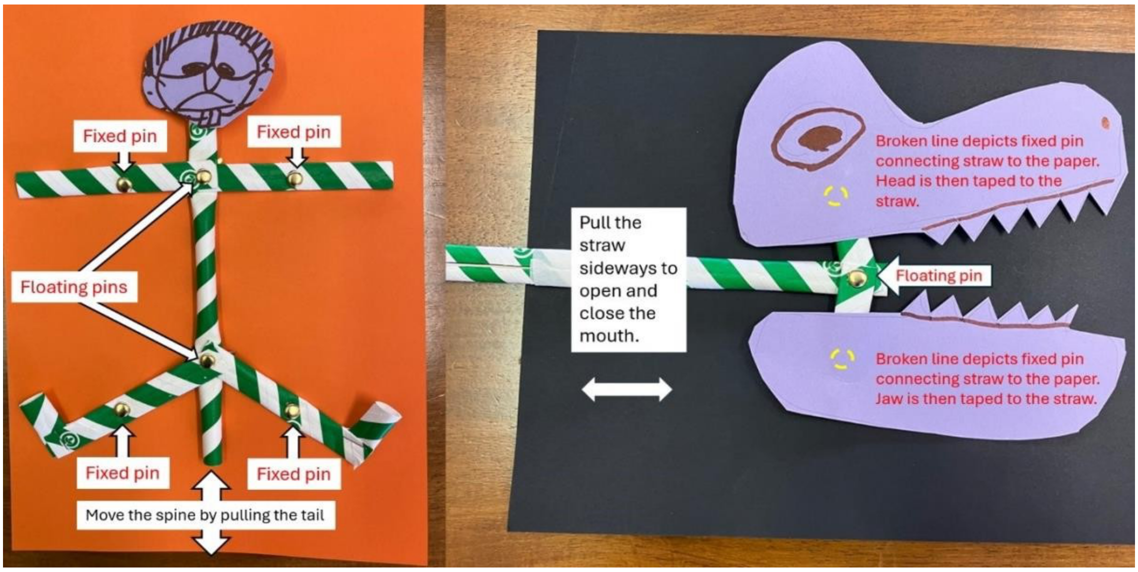

Fig. 2. *Mechanisms and linkages. Adapted from [8].*

Another popular option was to use disposable cups instead of the cardstock to create something resembling a freestanding toy. In these instances, pairs of holes on either side of the arms and legs provided fixed pivots without the use of split pins. A hole at the top was used for the spine onto which a head could be added. Some students soon realized that the backs of the cups could be removed to improve access for the puppeteer as the audience of the 'puppet show' only sees the front. The value of hands-on activities has been noted as they provide an "opportunity to test students' design thinking" [11]. The key teaching point is that linkages can change the direction of movement and forces.

Exploring the relationship between volume and surface area

The following activities are also included in SILO 6.3 'Nanotechnology'. An introductory activity to familiarize students with Pi (π) involves cups and string. Each student has their own cup and a piece of string. The string is wrapped around the circle and then cut to length. Students count how many times the string can be draped across the diameter of the circle as an approximation of π. Explain that the ratio of circumference to diameter is constant, and that this applies to all circles regardless of their size.

To explore the relationship between volume and capacity, the students participated in an activity called 'Mr. Wide and Mr. Tall'. Using a piece of paper, make a cylinder shape in either landscape (i.e., Mr. Wide) or portrait (i.e., Mr. Tall) orientation. Students do not need to make a bottom for their cylinders as the table will function as the bottom. Tops are not required for the cylinders as easy access is required to fill the cylinders with blocks. Although overlapping the paper will give the cylinders more rigidity and strength, direct students not to overlap the paper as this will reduce the capacity. Tape is used to join the two edges of the paper to complete the cylinder. Using small construction blocks, fill the Mr. Wide cylinder. Rather than counting these blocks, simply use the same blocks to fill the Mr. Tall cylinder after posing the question, "Let's find out if Mr. Tall holds the same, less or more?" The teaching point is that shape affects the volume too. Show the students the $V=\pi r^2 h$ formula, explaining that Mr. Wide had the greatest volume because there was an exponent affecting the radius.

A final discussion point about exponents in this sequence involves the permutations available for car registration plates. Pose the question, "How many permutations are there with a six- character number plate?" The actual answer is over 2 billion so ask the students to verbalize their thinking by using a formula rather than a number. Classroom discussions such as these affirm the approach taken by Díaz-Berrios and Martínez-Planell who emphasized the importance of meaning when learning about exponents [12]. Most students do not see that the answer is 36^6 so prompt them with a single character using only numbers (i.e., 10^1) and then proceed with two characters (i.e., 10^2) and then three (i.e., 10^3). Once students understand that 36 is derived from 26 (letters) + 10 (numbers), they can usually see why the answer is 36^6.

Conclusion and recommendations

Many of the activities from the circles and rotation unit were not included in this paper due to constraints of space but the listed examples provide a good cross section of the main ideas. Of note was that the learning sequences in this paper were always linked to prior knowledge using Hattan's broad definition as the "sum of what an individual knows" [13]. This was to maximize their confidence as they moved into new ideas and concepts.

In terms of scaffolding, perhaps we need to reconsider the prevailing idea of temporal assistance and expand our view to include a more forward-thinking approach where we prepare and support our students for the more complex STEM topics which they will encounter in middle school and high school. In this way we will be frontloading them for success [14]. As educators, perhaps we could also consider taking a more proactive approach to curriculum implementation where we seek to make important STEM connections, even if the current versions of our curriculum documents do not require it. In this sense we would be scaffolding learning beyond the immediate needs of our students to help them to thrive in the increasingly technological world in which we live.

This scaffolding can be a universally applied concept, from implementation in Australian primary classrooms and beyond. Just as these activities have been tested and implemented in classrooms in both Australia and Texas, it is recommended that they are also trialed in Canadian primary classrooms, to observe student learnings and responses to the early introduction of these activities and their wider application in STEM fields.

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