Gearing up for Robotics

An investigation into the acquisition of the concepts associated with gears by teachers in a constructionist robotics environment

Debora E. Lipson[1], John Murnane[2], and Anne McDougall[2]
[1]School of Education, Faculty of Arts, Education and Human Development,
Victoria University, PO Box 14428, Melbourne 8001, Australia,
debora.lipson@vu.edu.au
[2]Information & Communication Technology in Education and Research
Group, Melbourne Graduate School of Education, The University of
Melbourne, 3010, Australia, jmurnane@unimelb.edu.au,
a.mcdougall@unimelb.edu.au

Abstract. This naturalistic, qualitative research investigated the extent and depth to which the perceived embedded educational skills and concepts associated with gears in a robotics environment were realized. The research literature revealed a paucity and confusion of description and definition of gears, and a lack of articulation of the embedded skills associated with gears. Based on some seminal research papers, a novel skills grid was developed as a measuring instrument, against which deep mining of the knowledge progress of the understanding of gears of four teachers was observed. The analysis of results pertaining to considered gear integration in the construction of a robot revealed that learning does not occur serendipitously and, unless taught overtly, the opportunities for the learning of gear concepts are often missed or deliberately bypassed. This lack of desire to learn about, and consider gear integration in constructions, could be attributed to confusion of interpretation of a non-contextualised ratio, or more deeply, the confusion of ratio representation in rational number and colon formats.

1. Background

Robots are rapidly becoming an integral component of everyday life. In order to facilitate an understanding of this future environment, the study of robots, known as robotics, has become a growing field of interest and learning. Historically situated in information technology courses, robotics has developed from an element of investigation in control technology, to a compulsory, selected, or elective subject in schools at all levels. Over the last two decades the inherent complexity in the construction and programming components has been reduced, making the robotics educational environment more available and accessible for students of all ages. This multi-component approach to teaching and learning, situates robotics as both a process and a content curriculum, involving deliberation about the environment (group work, construction, problem solving), the material to be transmitted (physics, mathematics, spatial skills), and the method for transference of material (higher-order thinking skills, programming, and group work). Investigation into the learning opportunities revealed a plethora of skills, issues, and embedded knowledge including personal and inter-personal learning, and the studies of Mathematics, Science, English, History, and Sociology.

1.1 Claims

This emergent field of study has been supported by a developing literature of claims that robotics is rich in potentially embedded depth and breadth for the teaching and learning of a range skills and concepts including improvement in engagement [1, 2] and self-esteem [1]; improved problem solving skills [2]; improved understanding of scientific [2] and mathematics concepts [3-5]; and, close links with real life scenarios [1, 2]. These claims support the seminal ideas of Papert’s theory of constructionism [6], whereby construction of a publicly inspectable artefact is evidence of understanding the principles inherent in the artefact, and that learning occurs serendipitously in this environment.

This learning is evident in the cyclical processes of model generation, revision, and evaluation for model construction [7]. This perfect medium appears to enable deep understanding of the embedded concepts including the transmission of a deep understanding of simple machines. In spite of the increased interest in robotics in schools, little research appears to have been done in the short recent time to study the effect of this medium on the multitude of opportunities as touted in the literature [8].

1.2 Science Teaching

As part of a general science curriculum, it is seen as important that students develop knowledge, understanding, and appreciation, of machines in every day life, to raise their appreciation and understanding of the world they live in. The essence of these machines is the integration of simple machines i.e. gears, levers and pulleys, in various configurations. However, it appears that much of the science teaching about simple machines only emphasizes the mere recognition of gears, levers, and inclined planes, in everyday environments, and rarely addresses the scientific rationale and background of working machines [4, p23]. Further, even when there is a deeper investigation into the machinations of simple machines, instruction does not appear to be informed by the kinds of conceptions that children bring to the table [4, p23].

As a simple machine, although gears are small and apparently insignificant, they are the essential and most common components in the creation of a moveable model. An appreciation of the many various types of gears, gearing configurations, and their impact in everyday objects, is generally only studied to a superficial level and, unless there is a need to understand the intricacies of gearing to control the speed of motion of an object, students rarely gain the educational opportunity to investigate and encounter the many cognitive concepts embedded in a gears environment. With consideration for the provision of an engaging, manipulative environment that allows student exploration and contextualised learning, the construction of robots provides an ideal medium for the transmission of knowledge of contextualised simple machines.

1.3 Informal Author Observations

Over years of involvement in a robotics environment, the dichotomy between the potential and the observable skills acquisition has been raised. When students appeared to lack sufficient knowledge to appropriately integrate simple machines, they would select one of three alternative ways to compensate for this lack of understanding. These were modifying the robot construction; altering the programming; or modifying the original brief and objectives for the construction. Anecdotally, most students appeared to prefer the last option, with few students willing to reconstruct their models. These three tactics demonstrated two main problems: (i) the avoidance of good integrated use of gears through alternative modifications, and (ii) the non-realization of the skills and concepts embedded in this environment.

2. The Study

This study did not set out to establish a “truth or……build a warranted representation of the world” [9, p270]. Rather it set out to deliver a “story, … produce a narrative and give voice to different viewpoints or understandings” [9, p270], and investigate and analyze observations in the light of contextualised activities and constructions, seeking to reveal what gear concepts are manifested and learnt in this environment. It is essential at this point to clarify two aspects:- (i) the consideration of all aspects associated with gears, including descriptions, definitions, skills and concepts housed in these artefacts will be restricted to the educational setting, focusing on the gears contained in the LEGO® construction kit of ROBOLAB®; (ii) the gearing concepts, although sufficiently complex at a school level will remain at a relatively low level in comparison to gears used in heavy industrial machinery or cars by engineers, and are not extended to the full range of available, and more complex, engineering gears.

2.1 The Methodology

There are a large range of skills and abilities developed in a natural and collaborative construction and programming robotic environment. As such, the most appropriate way to examine acquisition of any skills and concepts is to observe and document any progress. Thus, to investigate any knowledge growth, a naturalistic qualitative study was conducted in situ, using a human as a researcher/evaluator/data collector [10, p124] to reveal the developing “story” of knowledge acquisition. Information was gathered by the participant observer through multiple sources of video capture, journals and pencil and paper tests.

2.2 Research Setting

Each week for a period of six weeks, four teachers attended a three-hour, after hours, *Robotics in Education* course as part of one of their selected academic subjects towards a higher qualification of a Masters of Information Technology in Education. They were presented with a series of construction and programming tasks of increasing difficulty and complexity, entwined with discussions of educational theory and issues, as raised through the literature. The construction component used the standard set of LEGO® construction kit called ROBOLAB®. The iconic programming language used was MindStorms® where, using the click and drag feature, icons representing motors, lights, and sensors were ‘placed’ on ports (input and output) in the programming sequence.

2.3 The Subjects

The focus on these self-motivated, articulate, and high achieving teachers, with divergent academic backgrounds and teaching foci, was seen as essential, as teachers are facilitators of student learning, guiding and directing knowledge acquisition. To support the inclusion and integration of robotics in an educational program, teachers need to be aware of the embedded skills and concepts, and ensure sufficient self-confidence to enable facilitation on this course. As teachers are more articulate than students, observation of teacher discussions and constructions, as indicative of their acquisition of gears skills and concepts, would provide greater insight into how students learn in this environment. Hence, a focus on teaching learning in this environment was seen as an opportunity to begin to create a rich and developing story of learning in a robotics environment.

2.4 Measuring Tools

The journal - as a component of assessment in this subject, the teachers were to develop a journal of reflection and planning. These journals were photocopied and used alongside the video to expand the analysis and development of each case study.

The pencil and paper test - based on a range of studies [3, 4, 11-13], pencil and paper tests are an accepted component for measuring and assessing knowledge of gears. Drawing on these tests, a pre and post-test was designed focusing on planar gear trains.

The video - in spite of some limitations associated with the use of a video to capture data, this method of data collection allowed the analysis and reporting of thick, rich descriptions of observations in a natural setting. It also provided opportunity to capture postures, gestures and interpersonal body language. Repeated viewings and analysis of episodic units enabled the development of deep probing and refined analysis after transcription of relevant units of discussions or constructions associated with gears and gearing. It also provided an opportunity to experience classroom events vicariously.

The grid - as preparation for the study, examination of the research literature and reference text books revealed a paucity and confusion of descriptions, definitions and identification of associated embedded concepts of gears. To enable clear articulation and measurement of the development of knowledge of gears, it became evident that there was a need to produce a grid that delineated the often overlooked and assumed understanding of gearing concepts. After analysis of a range of research papers that utilized gears as a testing medium, Lipson then developed the following novel evaluation grid (Table 1) [14].

3 The Results

As an evolving story of learning in a robotics environment, there were many observable outcomes in a number of areas. However, documenting and interpreting the learning process focused on gears revealed some significant results.

An analysis of the pencil and paper test revealed that little learning appeared to occur throughout the program. Review of the video during this testing phase provided some contrary and valuable insights into the diverse methods of solutions of gear ratios. ‘Talk-aloud’ protocols exposed obvious confusion between the reciprocal relationships of the ratio of cogs to the ratio of turns of planar gear configurations. Further confusion occurred when gears were not exact multiples of each other and resultant fractions were difficult to simplify.

Analysis of the weekly video data, as reported through the case studies, revealed some interesting issues related to the teachers’ learning outcomes as identified through the skills grid.

Identification

In spite of the expectation that teachers would have the ability to discern the exact difference between gears, it was found that there was consistent confusion and inability to identify and name the spur gears according to the number of cogs, or discern the function of the idler, bevelled edged, crown, worm, rack and differential gears. There was, however, a demonstration for an appreciation for the consistent relationship between the diameter and the circumference of a spur gear.

Motion

In general, the teachers understood the difference between rotational and linear motion when associated with the gross motion of a buggy travelling either in a straight line or turning a corner. However, there was some difficulty in appreciating that the rotational motion of gears created linear motion, and the use of a differential gearing configuration created pivotal motion where the object rotates on a fine point.

Causality

Adults have an intuitive appreciation for the requirement of gears to be connected (meshed) to produce motion throughout the construction (Connectivity). There is also an intuitive understanding that meshed gears results in simultaneous turning or motion (temporal causality), and that in a gear train the idler gears can be used as “spacers” between the initial point of motor contact (driver gear) and the desired point of action (follower gear).

Direction of rotation

Prompted by the pencil and paper tests, the teachers began thinking about the direction of rotation of meshed gears, and although construction further raised awareness of direction of rotation, they were unable to move beyond the ‘by inspection’ analysis to develop a generalised formulation.

Ratio

There are many opportunities for ratio learning in this environment. However, during construction there was no direct application to appreciate, or find, π (the mathematical ratio of circumference to diameter).

Teacher discussions revealed an obvious awareness of the identical ratio of turns for same sized gears, with explicit appreciation for different ratio of turns between different sized gears. Quantification of meshed planar gears of different sizes was, however, more difficult to calculate.

During construction, all teachers appeared to appreciate the non-effect on the ratio of idler gears, although this component was not evident in the pre or post-tests.

Regardless of size, same shaft gears initially produced ratio responses as if they were meshed planar gears.

The calculation of the gear ratio of a compound gear configuration was often difficult as it appeared to be based on the teachers poor understanding, and resultant lack of desire, to manipulate fractional rotations and their confusion between the two ratio formats (colon and rational number formats).

Problem solving

The teachers were unable to extract general solutions from a range of specific situations with regard to the rotational effect of idler gears. However, to enable calculation of the various planar and compound gear configurations all teachers decomposed the complex into parts.

4 Conclusion

Even though the teachers in the study were knowledgeable, self-motivated, articulate, and high-achievers, there was confusion in understanding and manipulation between a ratio presented in rational number format and a fraction. Further, there was a lack of durability and transferability of various gear concepts that demonstrated a fragility of concept retention.

This suggests that, for this study, construction in a robotics environment does not necessarily support the many claims of the embedded learning potential. It is obvious that there is a need for clear descriptions and definitions of gears and gear ratios, a need to ensure clear articulation of the two representations of ratios, and the need to identify the difference in operation and meaning between ratios and fractions. This indicates that there is a need for explicit teaching of ratios.

At the completion of the course there was an intensive analysis of the gear ratio of a compound gear configuration. The teachers then noted that this manipulative could be used as a visual representation for teaching fraction multiplication to students.

Identification	• One-to-one correspondence identifying and naming gears • Appreciation and identification of varying sized gears and the relationship between number of cogs on each gear and its size. • Appreciation for the relationship between the diameter and the circumference of a gear including the consistent relationship between the diameter and circumference for various sized gears.
Motion	• Understanding the difference between rotational (pivotal) and linear motion
Causality - *This involves understanding the need for connectivity for causality and the effect of this connectivity on direction of rotation*	
-Connectivity	• Recognition of effect of meshed gears vs. non-meshed
-Temporal Causality	• For planar gears: - simultaneous turning • For three or more gears in a gear train - effect of idlers as “spacers” • For compound gear configuration - emphasis on “use” to create movement in configuration
-Direction	• Opposing direction for sequentially meshed gears • Same direction for alternating gears • Same direction for gears (regardless of size) on same shafts • Use of worm gears to create unidirectional motion
Ratio	• Ratio of diameter to circumference to find π. • Ratio of turns for same sized and different sized meshed, planar gears • Ratio of same sized or different sized gears on a single shaft or axle • Calculating ratios for compounded gear configurations • Using ratio to enable an understanding of speed
Mechanical advantage	• Transfer force through the use of rack gears • Mechanical advantage
Higher order thinking (Problem Solving)	• Breaking whole into parts (decomposition) • Progress from specific to development of general rules (abstraction) • Development of symbolic representation (deduction) • Conditional statements • Prediction

Table 1. Novel grid of skills and concepts embedded in the use of gears

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