Cognitive load associated with proportional reasoning in enquiry-based learning: Randomized control design involving worked examples

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Purpose of Study

In recent years a global interest has emerged to improve the teaching of STEM (Science, Technology, Engineering and Mathematics) Education in schools. This need has been driven, in part, by the imperative to provide a workforce that can meet future economic and social needs (Caprile, Palmen et al., 2015). STEM Education has been seen as pivotal in influencing and guiding the development of STEM skills (National Science and Technology Council, 2013) through impacting school curricula (Pearson, Schweingruber et al., 2014). The escalation of STEM Education and subsequent urgency that has occurred has been the subject of much debate in recent research (Lamon, 2005; Steinthorsdottir and Sriraman, 2009). The argument for an integrated STEM curricula in Australia has been endorsed by recent government policy (Australian Government, 2016) and in particular by Australia's Chief Scientist who stated, "When students make subject decisions in secondary school, they are more likely to make choices that will be consistent with ultimately undertaking STEM related tertiary studies and careers if they understand the kinds of real world problems those careers might help them solve as adults" (Office of the Chief Scientist, p. 9, 2018).

The term STEM is generally accepted to encapsulate the combining of the disciplines of Science, Technology, Engineering and Mathematics, and while a credible argument can be made to define STEM through its association with these four disciplines, the term STEM Education implies a different association, one that is connected to practices related to teaching, pedagogy and curriculum.

Specific to STEM Education, is the critical question of whether teaching the disciplines of Science, Technology, Engineering and Mathematics should be taught in a STEM format or should be taught as the separate entities of Science, Technology, Engineering and Mathematics. To date, this question remains unresolved. To some extent this is because STEM Education is often taken to mean employing an integrated curriculum and this, in turn, is taken to mean incorporating activities, frequently discovery or enquiry-based, that promote cross-disciplinary transfer. Several educational programs to support the development of disciplines in STEM Education have been established. Research suggests discovery or enquiry-based learning has proven problematic (Schauble, Glaser et al., 1995) and this has given voice to those who question the effectiveness of types of learning methods (Kirschner, Sweller & Clark, 2006).

The challenge for educators and researchers is to determine how discovery or enquiry-based learning can be effective and to then develop programs that deliver the outcomes proscribed by government bodies and the broader education community to see Australia as STEM ready.

Based on previous research (Sweller, 1988) we contend that instructional strategies that adopt a discovery or enquiry-based approach may not be powerful enough to build the desired STEM schema, and that incorporating elements of explicit teaching into a predominately discovery or enquiry-based activity may enhance the likelihood of knowledge acquisition. Further we argue that Cognitive Load Theory (CLT) may hold the key to unpacking problems that call for the use of enquiry as, among other things, it seeks to explain the relationship between processing capacity of working memory and the development of schema that are needed for problem solving (Sweller, 2010).

Following this logic, our proposed study adopts the *eduKart* program, a program that connects real-life contexts through the building, testing and racing of an electric powered go-kart. It is a STEM program that is currently being taught and embraces teaching practices and techniques rich in STEM content but where it is perceived by the teachers of the *eduKart* program, that the participants involved in the program demonstrate little evidence of STEM learning after they have completed the program.

The program is closely linked to the Australian curriculum, focusing specifically on the disciplines Science, Technology, Engineering and Mathematics (STEM). *eduKart* is, therefore, ideally placed to evaluate the efficacy of an integrated curriculum. Teaching staff involved in the delivery of the program cite the acquisition of social and emotional skills commonly referred to as 21st Century skills as being the great strength of the *eduKart* program.

eduKart is delivered in a minimally guided environment, where the learners must discover information for themselves. The teaching staff involved in *eduKart* assert that whilst the program is STEM rich, the students show little evidence of knowledge acquisition particularly in the Mathematics and Science areas. Research undertaken by Kirschner, Sweller and Clark (2006) support this notion and state “based on our current knowledge of human cognitive architecture, minimally guided instruction is likely to be ineffective" (p.76). This and other researchers provide a firm evidenced based rationale to interrogate the *eduKart* program and investigate the assertions by the *eduKart* teaching team in relation to the position described by Kirschner, Sweller and Clark (2006).

We propose that as the students participating in the *eduKart* program are novices, they lack the appropriate schemas that would allow them to integrate new knowledge with their existing schema. We conjecture that the Cognitive Load (CL) involved in the first-time construction of a go-kart is sufficiently high as to place limitations on the learning of mathematical and scientific information. Schmidt, Loyens, et al. (2007) support this suggestion and state, "For novice learners, who lack proper schemas to integrate the new information with their prior learning, CLT suggests that the free exploration of a highly complex environment may generate a heavy working memory load that is detrimental to learning" (p. 93).

We further argue that the program can be restructured to incorporate sufficient guidance and explicit instruction without diminishing the enquiry-based nature of the program, in order to dramatically increase the likelihood of knowledge acquisition in these domains.

While *eduKart* engages in all four of the STEM domains, our study will focus on the Mathematics and in particular on the application of proportional reasoning. Within the *eduKart* program, students work with gears and investigate the effect they have on the performance of the vehicle. The students have no prior knowledge of gears and ratios, but are expected as a result of their *eduKart* experience, to have acquired an understanding of how and why gears are employed.

We argue that there are specific strategies such as a Worked Example (WE) that can be used to solve proportional reasoning problems in enquiry-based activities. This study involves incorporating WEs that are designed using the principles of CLT. We propose the use of a WE will reduce CL and students will have the available resources to allow new schema to be integrated more effectively. This proposed study will add further to the body of STEM Education and STEM curricula knowledge, investigating the acquisition of proportional reasoning schema through a the study of the *eduKart* program.

Methodology

The proposed methodology will use a similar research design adopted by van Gog et al. (2011) where participants will be randomly assigned into two groups (i) a treatment or worked examples (WE) and (ii) control or general enquiry based learning (EBL) group. All treatments will be carried out in a classroom using booklets and move through three phases: (a) a pre-test phase, (b) a learning phase, and (c) a post-test phase.

Rationale

Aim: To examine the effect of WE when undertaking a proportional reasoning STEM problem

Students undertaking complex discovery or enquiry-based activities are under high CL and available working memory for cross-disciplinary transfer and development of new knowledge is minimal. It is expected that employing CL sympathetic guidance through an explicit teaching component will better scaffold learning. As a result, group differences in CL ratings, near and far-transfer scores should be observed.

Table: The proposed research design

	Pre-test	**Learning Phase**	**Test Phase**	
			Near transfer	Far transfer
WE Group	x	Study worked examples	x	x
EBL Group	x	Solve problems using EBL	x	x

Note: WE: Worked Example; EBL: Enquiry Based Learning

<u>Learning phase</u>

Students will be given ten pairs of WEs. Each pair will include a WE (Appendix 1) followed by an isomorphic problem (Appendix 2) to solve with changes in the value of the two ratios. Following the completion of each WE and problem, students will be asked to rate the difficulty of the problems using a CL rating scale. Students in the Enquiry Based Learning (EBL) Group will solve the same problems using EBL methods.

Test phase

Immediately after the learning phase, students will be asked to solve ten problems that are similar to the acquisition problems (Near transfer problems). Seven days following the learning phase students will be complete ten more problems (Far transfer).

Data measures and analysis

Participants: Year 8 students

Independent variables: WE vs. EBL conditions

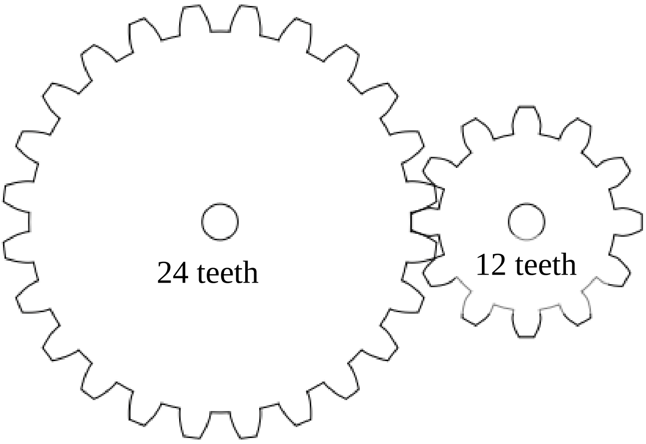
Dependent variables: Pre-test scores, EBL scores; Rating of CL; Scores on near transfer test, scores on far transfer test,

Data analysis -ANOVA

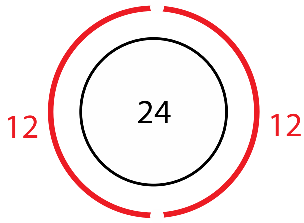
Subsequent experiments will follow an identical methodological format, each with one variable change to the explicit instruction method.

Appendix 1: CL task designed WEs

If the large gear (24 teeth) makes one full revolution, how many revolutions will the small gear (12 teeth) make? (24:12)



STEP 1



STEP 2

Teeth 24:12 Revolutions 1:2

STEP 3

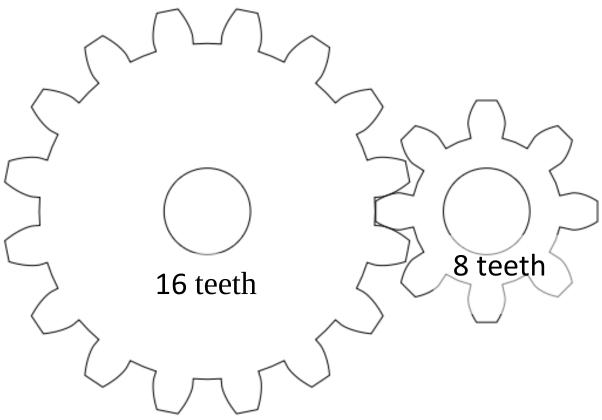
	Number of teeth	Number of revolutions
	24	1
	12	2
Ratio	2:1	1:2

STEP 4

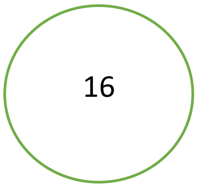
Answer: The small cog makes 2 revolutions in inverse proportion to the number of teeth on each cog.

Appendix 2: Isomorphic problem

If the large gear (16 teeth) makes one full revolution, how many revolutions will the small gear (8 teeth) make?



STEP 1



STEP 2 Teeth 16:8 Revolutions __: __

STEP 3

	Number of teeth	Number of revolutions
	16	
	8	
Ratio	2:1	

STEP 4

Answer: The small cog makes _____ revolutions in inverse proportion to the number of teeth on each cog.

How easy or hard was this problem? Please circle your answer

Extremely easy	Very easy	Easy	Neither hard nor easy	Hard	Very hard	Extremely hard

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