Gender differences in perceptions of the use of faded worked examples in mathematics

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Drawing from cognitive load theory, the worked example effect details how studying worked examples allow for greater learning gains than traditional problem-solving practices for novice students or those of low prior knowledge. A classroom-based intervention was conducted with 223 students between the ages of 14-15 years old, and their teachers from two schools of different socioeconomic standing in South Africa. Faded worked examples were used as the medium of instruction. In contrast to the pre-test results, female students outperformed males in the post-test. Female students and those from a low socioeconomic background also found faded worked examples significantly more beneficial for their learning than male students and those from a higher socioeconomic status. Consequently, the use of faded worked examples may improve the mathematics performance for female students and those of low socioeconomic status and highlight that the worked example effect may be more prevalent among these groups of students.

Keywords: cognitive load theory; worked examples; mathematics; classroom intervention

Introduction

Many educational theories fail to find relevance and impact within classroom teaching settings; however, cognitive load theory (CLT) has gained considerable traction here, with several books being written on the subject specifically for teachers (Garnett, 2020; Lovell, 2020). Since its development in the late 1980s by John Sweller (Sweller, 1988), the instructional guidance outlined within CLT has been extensively tested within many subject domains and with students of many different ages (for a current review of CLT, see the Special Issue: Cognitive Load Theory (Ginns & Leppink, 2019)). CLT is now easily accessible to academics and teachers alike, and insights from teachers and students documenting its effectiveness in organic classroom situations can now be included in academic literature. This paper reports on one such study and aims to add ecological validity to the existing literature on CLT by applying its principles in a natural classroom setting.

Cognitive Load Theory

Memory forms the basis of learning, and it seems logical that this aspect of human cognitive architecture should be taken into account when designing effective instructional resources for the classroom. Although the structure of human memory is still a subject of ongoing debate, it can be seen to comprise of sensory, short-term (including working memory) and long term memory (Baddeley et al., 2020). CLT works within this theoretical memory structure and details how unnecessary cognitive load on working memory can be mitigated in learning environments to improve learning (Sweller, 2010a). Initially, cognitive loads were categorised into three main types: intrinsic, extraneous and germane. Intrinsic load can be seen as the inherent difficulty of the material to be learned, whereas extraneous load is that imposed by poor instructional design. Germane load refers to what is left of working memory capacity after intrinsic and extraneous loads have been applied (Sweller & Chandler, 1994). However, Sweller (2010b) later explained how germane load is “not an independent source of cognitive load like intrinsic and extraneous cognitive load”; thus, its use in Sweller’s published works ceased from 2010 onwards. Currently, the central premise of CLT surrounds the optimisation of intrinsic load and reduction of extraneous load (Lovell, 2020).

Since its inception in the 1980s, CLT has continued to evolve. Prior to 1998, there were only 7 documented instructional strategies or effects that were seen to impact on cognitive load. Currently, there are now 15 documented effects (Sweller et al., 2019). One of the earliest documented instructional strategies was the worked example effect which details how studying worked examples is more beneficial than conventional problem solving strategies for novice learners (Sweller & Cooper, 1985).

The worked example effect

As one of the original seven cognitive load effects documented in 1985, the worked example effect occurs when studying worked examples allows for greater learning gains than traditional problem solving approaches (Sweller & Cooper, 1985). In this seminal paper, Sweller and Cooper (1985) found that when worked examples were used to teach algebra to secondary school and university students, not only did these students solve subsequent problems more rapidly, but they also did so with fewer mathematical errors than those who were taught using conventional problem solving methods. Sweller et al. (2019, p.265) posit that these increased learning gains are due to the ability of worked examples to focus student attention on the procedures that need to be learned:

> In contrast to conventional problems, worked examples focus the learners’ attention on problem states and associated operators (i.e. solution steps), enabling them to induce generalised solutions. Thus, studying worked examples may facilitate knowledge construction and transfer performance more than actually solving the equivalent problems.

The worked example effect has been documented in many domains. Within mathematics, there are several studies that document positive learning gains from the use of worked examples with secondary school students (Bokosmaty et al., 2015; Rentowati et al., 2017). However, it must be noted that the use of worked examples is not recommended for high attaining students who already have a good understanding of the material to be learned, as “analyzing a redundant worked example and integrating it with previously acquired schemas in working memory may impose a greater cognitive load than problem solving” (Kalyuga et al., 2003, p. 27). Thus, the use of worked examples can be seen to benefit low attaining students with poorly defined mental representations (or schemas) of current or previously learned work.

Faded worked examples

The concept of faded worked examples and forward and backward fading was first introduced by Renkl et al. (2002), who posited that as the level of student knowledge increases, the guidance offered in instruction should decrease. The authors found that both types of faded worked examples promoted learning and performance in similar questions (near transfer), but backwards faded examples offered greater performance measures in a post-test. Hesser and Gregory (2015, p.36) state that "[f]aded worked examples are similar to worked examples but fade out steps for students to complete, allowing support within the problem-solving approach as learning improves." Thus, as students' progress in knowledge acquisition and schema development, they should complete the missing steps of faded worked examples in which "the number of blanks is increased step-by-step until the whole problem needs to be solved", thus providing a "smooth transition from studying examples to working on incomplete examples, to problem solving" (Renkl & Atkinson, 2010, p.99). Faded worked example design has been described in one of two ways: forwards versus backwards fading (Renkl, Atkinson, Maier, & Staley, 2002) and slow versus fast fading (Reisslein et al., 2007).

Despite many randomised control trial-type studies showing CLT's effectiveness as an instructional strategy, many have failed to omit possible effects of student gender and socioeconomic status. Current research in CLT suggests that our biological makeup, as shaped by evolutionary processes, may affect how males and females think, learn and understand (Geary, 2008; Paas & Sweller, 2012). In line with this, Bevilacqua (2017, p.190) postulates that the biological differences between male and female brains are suggestive of differential cognitive processing and states that "[t]here is enough evidence in the literature to support the inclusion of gender differences in cognitive load as a further upgrade to cognitive load theory." In addition to this, student perspectives on its use in the classroom, such as those offered by Reisslein et al. (2007), are seldomly reported in the literature. This study aims to address these shortfalls in the literature.

The Study

The study aimed to elicit 14-to 15-year-old student perceptions on learning how to simplify algebraic fractions through the use of faded worked examples without the assistance of their teacher or peers. Two schools from South Africa were selected. School A is a privately funded day school that admits students of a high socioeconomic status (SES). Five teachers took part with 115 students (45 males and 70 females). School B is a government-funded day school that admits students of low SES, of which 108 students (59 males and 49 females) and 3 teachers took part. Before the intervention took place, a pre-test on algebra and fractions was administered to determine participant prior knowledge levels (PKLs).

Additionally, pre and post surveys were administered to collect background information and initial thoughts towards the intervention. For the intervention, students completed a printed booklet that included a series of backwards faded worked examples on the simplification of algebraic fractions as would be found in the South African curriculum. These were completed by the students in one lesson, without assistance from peers or their teacher. In the following lesson, students then completed a post-test to determine if they could simplify algebraic fractions. In this post-test, students were asked to simplify seven algebraic fractions where only the question-state was posed.

Findings

From the pre-test on prior knowledge, students were divided into 3 PKLs based on their performance: PKL1 $(0-54\%)$, PKL2 $(55-70\%)$ and PKL3 $(71-100\%)$. These PKL cut-off values were derived by dividing the pre-test data into thirds. As noted by

Reisslein et al. (2007), the criteria by which student PKLs are classified is an area of CLT research that needs further consideration as it is not consistent throughout the literature. Male students outperformed female students in the pre-test, but not the post-test. To determine if these differences were significant, a one-way between-group analysis of variance was done. Significant gender differences were found in the pre-test: ($F_{[1,199]} = 6.39; p = .01$), but not the post-test: ($F_{[1,194]} = 0.82; p = .4$). Despite significant differences between male and female students being evident, the effect size of this difference, using eta-squared, was only $.031$. However, what is interesting to note is female students (59%) outperformed males (57%) in the post-test – a result that contrasts with the average pre-test performances where females scored on average 5% below their male counterparts.

To account for the differences seen in the pre and post-test results, 200 student responses on the post-intervention questionnaire were analysed. Figure 1 shows the percentage of students who indicated if worked examples helped them learn how to simplify algebraic fractions or not. A Chi-square Test for independence indicated that there were significant differences between male and female responses, (${\chi^2}_{[1]} = 6.4;\ p = .01;\ phi = .19$), with more females stating that worked examples helped them learn how to simplify algebraic fractions.

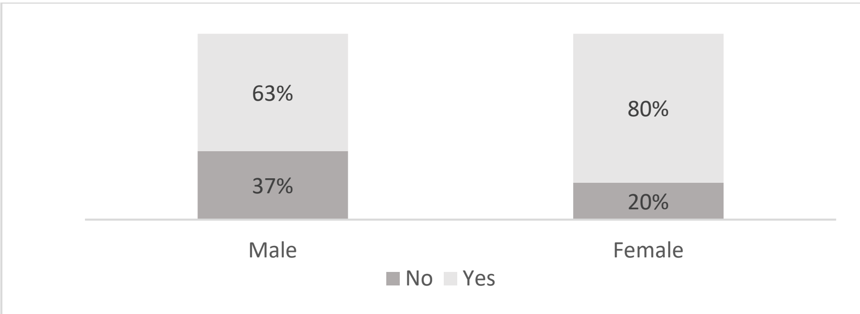

Figure 1 – "Did you find that completing the worked examples helped you understand how to do algebraic fractions?"

When these results are further broken down according to student PKLs, as seen in Figure 2, it is clear that female students within each group feel that using worked examples helped them learn how to simplify algebraic fractions, more so than their male counterparts. The difference in responses between males and females, although not reaching significant levels of difference, highlights that female students, more so than males, feel that using worked examples helps them learn how to simplify algebraic fractions.

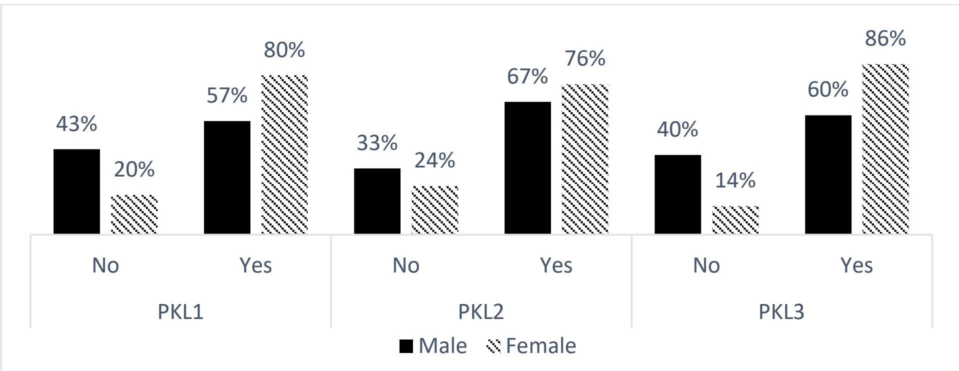

Figure 2 – "Did you find that completing the worked examples helped you understand how to do algebraic fractions?"

Students were then asked if they would like worked examples to be used in class again, with results shown in Figure 3. Overall, low SES students are significantly more likely to say they want worked examples to be used again in class when compared to high SES students: ($\chi^2_{[1]} = 35.28;\ p < .001;\ phi = -.43$). Significant gender differences were also evident for low SES students: ($\chi^2_{[1]} = 5.7;\ p = .017;\ phi = .276$) with 90% of female students indicating they would like worked examples to be used again in class.

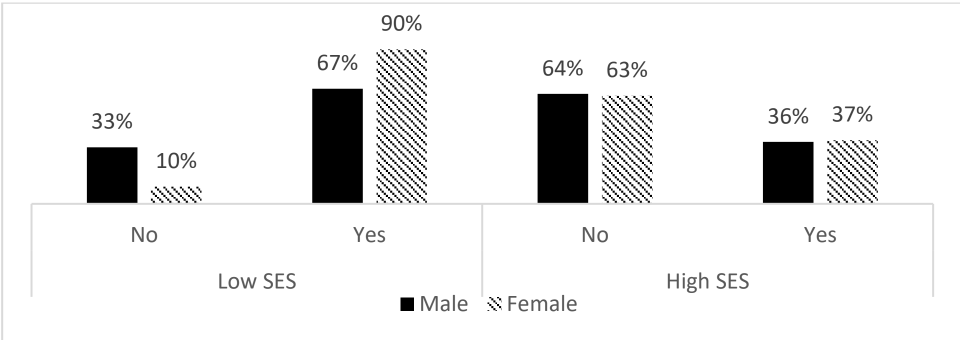

Figure 3 – "Would you like your teacher to use worked examples like this more in class?"

Conclusion

Female students appear to prefer the use of faded worked examples when compared with male students. A significant majority of female students indicated that completing the faded worked examples helped them learn how to simplify algebraic fractions without assistance from peers or their teacher. Female students from high prior knowledge levels also indicated that worked examples helped them learn how to simplify algebraic fractions. These more qualitative results contrast with current literature, which suggests that the use of worked examples only benefits students of low prior knowledge. Significant gender differences were also evident when comparing students of different socioeconomic standing, with almost all female students indicating they would like worked examples to be used again in class. These results highlight that the worked example effect may be more prevalent among female students and those of a lower socioeconomic status.

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