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The Effectiveness of Metacognitive Prompts on a Genetics Test among High School Students in Kenya

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Abstract: This study investigated the effectiveness of using metacognitive prompts in improving scores on a genetics test among high school students in Western Kenya. The study, a post-test only control group quasi-experimental design involving 2x2x3 factorial matrix also investigated the interacting effects of metacognitive prompting and self-efficacy beliefs while controlling for gender. A total of 2,139 form four (grade 12) students from intact classes participated in the study that was carried out in 17 high schools. Three validated instruments: Metacognitive Prompting Questionnaire (MPG), Self-efficacy Questionnaire (SEQ) and Genetics Test (GT) were used for data collection. Data were analysed both descriptively (means and standard deviation) and inferentially through a 2x2x3 Analysis of Covariance (ANCOVA). Findings showed that testing method(Metacognitive prompting Versus Conventional) and self-efficacy beliefs had statistically significant main effects on students genetics test score ($F(1,2132) = 4.568$, $p = 0.033$) and ($F(1,2132) = 963.740$, $p < 0.001$) respectively. This implied that use of metacognitive prompts had superior effects to conventional method of testing. It also implied that students who are highly efficacious do better on tests than students with low self-efficacy. There were no significant 2-way and 3-way interaction effects of variables on genetics test score. These findings have implications for Biology teachers who are implored to adopt the use of metacognitive prompts during testing and to promote self-efficacy beliefs among students.

Keywords: Metacognitive prompts, Self-efficacy, Genetics, Testing

Introduction

One of the main objectives of science education is to help students to become independent, autonomous, efficient and life-long learners (Donnelly 2010; Kozma 2013; Kuo et al. 2013). According to Watkins (2001), to promote learning one has to make learning explicit and to bring learning itself to consciousness. To achieve this, many, educators and psychologists have long promoted the effective role of cognitive and metacognitive strategies in teaching and learning. Learning in science involves various cognitive processes required in problem solving, inquiry learning, reading and writing (More & Hill 2002; Veenman 2012). To improve science education it is imperative to develop learners' metacognitive awareness by guiding them to be responsible for their own learning through being able to plan, monitor and evaluate their learning (Chiu 2007; Sandi-Urena,Cooper& Stevens 2011;Zohar & Barzilai 2013).

Certain aspects of learning such as problem solving, critical thinking and self-directed learning are critical for preparing students for higher education and career (Donnelly 2010; Fisher 2011; Lai 2011). A host of research have shown that meaningfulness of learning can be empowered by metacognition (Collins 2011; Lai 2011; Ozsoy & Ataman 2009; Schraw & Dennison 1994). Conceptualisation of metacognition over the past three decades by researchers (Balcikanli 2011; Flavell 1979; Schraw 1998; Schraw & Dennison 1994; Thomas, Anderson & Nashon 2007; Veenman 2012) highlights the interrelationships of metacognitive knowledge and skills (Veenman et al. 2006). Metacognition includes the metacognitive skills which are denoted to as "executive or self-regulatory processes" (Veenman 2012, p.21). Several metacognitive strategies empower metacognitive knowledge and skills in science education like prompted reflection questions (metacognitive prompting), modeling, thinking aloud, metacognitive scaffolding and self-questioning (Du Toit 2013; Haidar & Al Naqabi 2008; Ku & Ho 2010; Mevatech & Fridkin 2006; Parsons 2011).

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Metacognitive Prompting

Metacognitive prompting' is defined as "an externally generated stimulus that either tacitly or explicitly activates reflective cognition or evokes strategy use with the objective of enhancing a learning or problem solving objective" (Hoffman & Spatariu 2008, p.878). Metacognitive prompting has been proved as effective in enhancing students' self-efficacy and problem solving efficiency in science and mathematics (Collins 2011; Hoffman & Spatariu 2008). Prior studies have revealed the inclusion of metacognitive prompts during assessments resulted in superior problem solving performance (Hoffman & Spatariu, 2008; Kramarski & Gutman; 2006). Hoffman & Spariatu, (2008) showed that metacognitive prompting promoted both accuracy and efficiency in problem solving for students in math classes. Endorsing "prompted metacognitive reflections" (Collins 2011, p.39) by asking students reflective questions as they work their way through learning, triggers their reflective cognition and helps to connect their learning experience and content knowledge to unfamiliar contexts (Collins 2011; Davis 2003; Hoffman & Spatariu 2008; Wiezbicki-Stevens 2009). According to Berthold, Nückles & Renkl (2007) cognitive and metacognitive prompts empower students' learning especially when metacognitive and cognitive prompts are combined. Prompting has been used to get students to think, review and reflect before, in or after the lesson to deepen understanding and comprehension (Fogarty 2006, p.8). Self-reflection questions and comments by naming and describing while learning help the students to better understand when there is any difficulty, their reflective cognition and helps to connect their learning experience and content knowledge to unfamiliar contexts (Collins 2011; Davis 2003; Hoffman & Spatariu 2008; Wiezbicki-Stevens 2009). Metacognition does not influence learning outcomes when it is isolated but rather is related to other elements of learning theory such as self efficacy (Veenman 2012).

Metacognition and Self-efficacy

Research has shown a relationship between metacognitive awareness, self-efficacy, self-regulation and learning processes (Lai 2011; Veenman, Van Hout-Wolters & Afflerbach 2006). Students' metacognitive awareness and the metacognitive strategies that they use in learning processes are subsets of self-regulation such as self-efficacy, where the learner's self-confidence about performance and goal attainment influence the learning outcomes (Lai 2011; Schraw, Crippen & Hartley 2006). The role of student's self-efficacy in empowering academic outcomes has been proven where students with high level of self-efficacy often persevere longer with tasks, and are more likely to set and monitor their goals (Bandura 2006; Collins 2011; Britner & Pajares 2006; Zimmerman & Cleary 2006). While metacognitive awareness plays significant role in self-regulated learning, self-efficacy is important to help the learners to have the belief that they can perform tasks an achieve goals (Zimmerman & Cleary 2006). The learners with less successful strategies are the individuals that have low level of self-efficacy (Collins, 2011). Self-reflection on performance is the last stage of self-regulation where the learner evaluates the extent of their satisfaction about performance outcomes and it is found that self-efficacy plays a crucial role at this stage because it influences the learners' abilities to judge their task performance and goal achievement (Collins 2011, p.28). In this light, teacher's feedback to students increases their self-efficacy(Zimmerman & Cleary 2006). What leads to the empowerment of learners' self-efficacy is the goal achievement coupled with the cognitive processing that is required to achieve the targeted goal (Collins 2011, p.37).

Although several studies investigated the role of metacognition in teaching and learning, the effect of implementing certain metacognitive strategies such as metacognitive prompting in specific tasks such as testing has not explored deeply and openly in the literature (Lai 2011; Zohar & Barzilai 2013). In addition,few studies have explored the effect of metacognition on academic outcomes among high school students. The current study investigated the effectiveness of metacognitive prompting in a problem solving task measured through a genetics test and its interactive effects with self-efficacy. Gender was controlled for since gender differences seem to play a role in the level of the student's self-efficacy, although literature review indicated inconsistent results (Zimmerman & Martinez-Pons 1990; Jacobs et al. 2002). A study by Pajares (2003) concludes that although grade nine female students obtained better writing scores, the male students showed a higher level of self-efficacy than the female students. Another study (Zimmerman & Martinez-Pons 1990) indicates that there is no significant difference in self-efficacy in mathematics between male and female students while Jacobs et al. (2002) concludes that female students have higher self-efficacy than males from kindergarten through grade twelve in mathematics. The purpose of this study was to investigate the effectiveness of metacognitive prompts in a genetics test among high school students in kenya.

Method

Research Design

This study used a randomized control group quasi-experimental research design involving 2x2x3 factorial matrix with gender serving as a covariate. The design involved a full factorial model that investigated the main effects of the experimental treatment (metacognitive prompting), gender, and self-eficacy beliefs on genetics problem solving. Quasi-experimental design was appropriate for this study because randomly assigning individual participants to experimental and control conditions was impossible due to the nature of pre-existing intact classes of students (Johnson & Christensen, 2004). Seventeen high schools in Kenya agreed to participate in the study. From those schools, classrooms were randomly assigned to the experimental and control conditions by a member from each class drawing a 'YES' or a 'NO' token from a hat. Students in the 'YES classes' were assigned to the experimental group while those in 'NO classes ' were assigned to the control group. The result was two equivalent groups of students in the experimental and control conditions drawn from each school. Genetics instruction for both groups conformed to standards included in the national curriculum. The experimental group received metacognitive prompts embedded in their genetics test, while the control group received their test without any metacognitive prompting.

Participants

A total sample of 2,139 form four (12^{th} grade) was purposively selected from a population of approximately 4,000 form fours, from 17 high schools in Western region of Kenya. This was because genetics is taught at form four level (grade 12).There were n= 1070 (50.03%) males and n= 1069 (49.97%)females based on the current demographics of the school then.

Data Collection

In addition to providing individual demographic information, students in the study completed three validated instruments: Metacognitive Prompting Questionnaire (MPG), Self-efficacy Questionnaire (SEQ) and Genetics Test (GT) were used for data collection

Metacognitive Prompting Questionnaire

Metacognitive Prompting Questionnaire was a 14-item questionnaire. The metacognitive prompts, included comprehension questions, strategic questions, reflection, and connection questions, to be completed during the problem solving tests. Two comprehension questions were designed to encourage students to reflect on a problem before solving it. Four strategic questions were designed to encourage students to think about what strategy might be appropriate for the given problem and to provide a reason or rationale for that strategy choice. Four reflection questions were designed to foster self-monitoring, self-explaining, and self-evaluation in the problem solving process. Finally, four connection questions were designed to encourage students to identify and recognize deep-structure problem attributes so that they could activate relevant strategy and background knowledge. In terms of performance for the different types of MP, strategic MPs tended to perform better than the rest with a cronbach's alpha of 0.76, followed by reflection MPs with an overall alpha of 0.74, then comprehension with alpha of 0.72 and finally connection MPs with alpha of 0.69.

Self-Efficacy Questionnaire (SEQ)

A Self-efficacy Questionnaire was used to measure students' self-efficacy beliefs about their genetics problem solving ability. This questionnaire is a modified version of the Self-efficacy and metacognitive Learning Orientation Inventory- Science (SEMLI-S) developed by Thomas., Anderson, & Nashon, (2007) and used in assessing the self-efficacy beliefs of students in science. The SEQ was developed by the researcher by modifying items from three sub-scales of Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) to make it applicable to the study population and relevant to the research questions. SEMLI-S is a valid and reliable tool for investigating high school students' self-perceptions of elements of their metacognition, self-efficacy and science learning processes. Modification of existing assessment instruments and outcome measures is common practice; this frequently occurs to render a measure more closely suited to the specific purposes and environment for which it is intended and such that it answers the specific questions it is intended to answer (Kazdin, 1999). According to Kazdin (1999). such adaptations, when relevant to a particular setting, are justifiable insofar as the changes are necessary. This modified version was named Self-efficacy Questionnaire (SEQ) with three sub scales, science self efficacy (SSE), self regulation (SR), and constructivist connectivity (CC). Internal consistency for the modified scale in the current sample was above the acceptable levels: Science self-efficacy, α=0.873; Self-regulation, α=0.922; Constructivist Connectivity, α=0.917; Overall Self-efficacy scale, α=0.946. The final instrument had 25 items on a 5-point Likert-type scale: *1 = Strongly Disagree (SD); 2 = Disagree (D); 3 = Uncertain (UN); 4 = Agree (A); and 5 = Strongly Agree (SA)*

Genetics Problem Solving Test (GPST

The Genetics Problem Solving Test (GPST) was an 18-item classroom assessment focused on solving problems from the domain of genetics. The questions fit within HS-LS3 in the NGSS (National Research Council, 2013). Both face and content validity were achieved through expert review using same experts as those for BAT. The rater's report for GPST indicated that the items were rated relevant, with the mean rating ranging from 2 (relevant) to 3 (highly relevant).The overall mean rating was 2.83 on a scale of 1 to 3. There were two forms of the GPST, which served as the intervention under investigation in this study. The Metacognitive Prompting Questionnaire (MPQ) is a 14-item survey with reliability co-efficient of 0.78. The 14 items were embedded in the GPST for experimental group; serving as an intervention. Details of MPQ are found in the next section.

Data Analysis

Data were analysed both descriptively (means and standard deviation) and inferentially through a 2x2x3 Analysis of Covariance (ANCOVA).

Results and Discussion

Results and discussion of findings are presented in this section. Data were analyzed both descriptively (means and standard deviation) and inferentially using a 2x2x3 Analysis of Covariance, ANCOVA(between-subjects factor: Test method (Metacognitive prompting and conventional method of testing), Self-efficacy Beliefs(Low, Moderate and High) and a covariate: Gender(Male and female).

Preliminary Findings

Demographics of participants were assessed to ensure almost equal representation by gender and treatment groups. Underlying assumptions for ANCOVA were examined to ensure that the data did not violate them. In addition, to understand the central tendency and variability of the data, descriptive analysis was conducted to give means and standard deviations.

Demographics of Participants

A total of 2,139 participants were involved, with n=1081 in experimental group and n=1059 in control group. There were n= 1070 males and n= 1069 females. These results indicate good enough representation by gender and by treatment groups.

Testing for Assumptions

Assumptions of Normality and homogeneity of variances were assessed through Q-Q plots and Levene's test respectively. Q-Q plots revealed that data were Normally distributed. results of Levene's test were not statistically significant ($F(1,2137)=.001$; $p=.978$). This meant the assumption of homogeneity of variances was not violated and that data were suitable for ANCOVA.

Descriptive Statistics

Table 1 presents descriptive statistics of the variables of interest. Means, standard deviations and sample sizes for respective cells are indicated.

Table 1. Means, standard deviations and sample sizes for genetics test by treatment group and level of self-efficacy beliefs

Level of Self-Efficacy	Group	Mean	Std. Deviation	N
Low	Experimental	11.93	5.687	111
	Control	11.37	4.126	170
Moderate	Experimental	27.54	6.334	917
	Control	26.32	6.590	862
High	Experimental	37.12	2.684	52
	Control	34.89	6.216	27

Results indicate that students in experimental group outperformed those in control group regardless of whether they had low, moderate or high self-efficacy beliefs. The significance of this difference was investigated through inferential analysis. Overall mean for Students' self-efficacy beliefs was M= 74.23, SD= 18.912 with a minimum score of 25 and a maximum of 125; while that for Genetics test was M=25.28, SD=8.376 with minimum score of 2 and maximum of 40.

Primary Findings

Summary of the analysis of covariance is presented in Table 2. This is to explain the hypotheses involving main and interaction effects of testing methods (TM), gender (GEND) and self efficacy beliefs (SEB) on students' Score on Genetics test (SGT)

Table 2. Summary of analysis of covariance on students' genetics test scores according to testing methods, self-efficacy beliefs and gender

Source of Variation	df	F	Sig.	Ŋ^2
Main Effects				
TestMeth	1,2132	4.568	.033*	.002
SEB	1,2132	963.70	.001*	.311
GEND	1,2132	1.03	.31	.000
2 Way Interactions				
TestMeth * SEB	5	.32	.57	.000
SEB * GEND	2	.29	.59	.000
TestMeth*GEND	1	.159		.690
3 Way Interaction				
TestMeth * SEB * GEND	1,2132	.12	.73	.000

* means statistically significant at $\alpha = 0.05$

Results in Table 2 reveals statistically significant main effects of testing method ($F(1,2132) = 4.568$, $p = 0.033$, Ŋ^2= 0.002) where the students in experimental group did better (*EMM*= 25.466) than those in control group (*EMM*= 24.139). Even though the effect size was weak; Ŋ$^{2=}$ 0.002. This finding may prove to be of minimal practical significance, but does bear some attention in future studies exploring the impact of metacognitive prompting in different academic populations and situations.

There was a statistically significant main effects of self-efficacy beliefs ($F(1,2132) = 963.740$, $p < 0.001$, Ŋ^2 = 0.311) on students genetics test score where students with high SEB outperformed (EMM= 35.892) those with moderate (*EMM*=26.903) and low SEB (*EMM*= 11.613) in that order.

The predicted main effect for gender was not significant ($F(1,2132) = 1.03$ $p = 0.31$, $\eta^2 < 0.001$).

The summary of ANCOVA results of the 2-way interaction effect in Table 2 revealed no significant interaction effect of testing methods and SEB on the students' SGT ($F = 0.32$, $P > 0.05$), hence the Null hypothesis is not rejected. Therefore Testmeth and SEB did not interact to have significant effect on students' SGT. This implies that students' SGT did not differ irrespective of their level of self-efficacy when they are exposed to either the metacognitive prompting or conventional method of testing. This means that none of the treatment conditions was particularly superior over the other for any of the level of self-efficacy.

The summary of ANCOVA results of the 2-way interaction effect in Table 2 revealed no significant interaction effect of SEB and GEND on the students' genetics Test scores in, ($F = 0.29$, $P > 0.05$), hence the Null hypothesis is not rejected. This implies that SEB did not interact with gender to influence students' score on genetics test. In other words, SEB were not differentially effective for any of the gender. This means that with respect to student's gender, the level of self-efficacy beliefs did not have significantly different impacts on genetics test scores.

Similarly, summary of ANCOVA results of the 2-way interaction effect in Table 2 revealed no significant interaction effect of Testmeth and gender on students' score, ($F = 0.514$, $P > 0.05$), hence the Null hypothesis is not rejected. This explains that there was no significant difference in the students' genetics test score based on gender when they are exposed to either the metacognitive prompting or conventional method of testing. In other words, none of the treatment conditions was particularly superior over the other for any of the gender.

The summary of ANCOVA results of the 3-way interaction effect in Table 2 revealed no significant interaction effect of Testmeth, gender and self-efficacy beliefs on students' genetics test scores, ($F = 0.12$, $P > 0.05$), hence the Null hypothesis is not rejected. This by implication explains that testmeth, gender and self-efficacy beliefs do not interact to significantly influence students' score in genetics. The implication is that none of the possible 12 combinations of treatment, gender and self-efficacy beliefs do not work together to influence performance during testing.

Discussion

This study investigated the effectiveness of using metacognitive prompts in improving scores on a genetics test among high school students. The ANCOVA model used in this investigation allowed the control for effects of gender and test for effects of metacognitive prompts during testing and self-efficacy beliefs during a genetics test. The results suggested that metacognitive prompting is beneficial in supporting student performance on the genetics test, regardless of the condition. In addition, students who are highly efficacious did better than those with moderate and low self-efficacy in this sample drawn from Kenyan high school students. The findings are consistent with prior studies that revealed the inclusion of metacognitive prompts during assessments resulted in superior problem solving performance (Hoffman & Spatariu, 2008; Kramarski & Gutman; 2006; Kramarski & Zeicher, 2001). A study by Hoffman & Spariatu, (2008) showed that metacognitive prompting promoted both accuracy and efficiency in problem solving for students in math classes. The results are also consistent with Schraw (1998) who recommended providing explicit prompts to help students improve their regulating abilities. He suggested using a checklist with entries for planning, monitoring, and evaluation, with sub-questions included under each entry that need to be addressed during the course of instruction. Such a checklist, he argued, helps students to be more systematic and strategic during problem solving. Similarly, Schraw et al. (2006) and Schraw (1998) urge educators to provide explicit instruction in cognitive and metacognitive strategies. These results have implications to classroom teachers who can effectively include metacognitive prompts in tests to guide students to activate the problem solving strategies they have learned during their studies

Conclusions

Metacognitive prompting seems to have influenced the performance of students during genetics problem solving test. This finding may prove to be of minimal practical significance owed to the small effect size, $\eta^2 = 0.002$, but does bear some attention in future studies exploring the impact of metacognitive prompting in different academic situations. in addition, self-efficacy seems to have an effect on students' outcomes in a test. These findings lend support to the use of metacognitive strategies in both learning and assessment. It may appear that students who perform well in test apply their metacognitive strategies and are highly efficacious.

Recommendations

Because literature shows that metacognitive prompting leads to meaningful problem solving and with the findings of this study that metacognitive prompting significantly influenced performance on a test, it is recommended that biology teachers should embrace metacognitive prompting strategy and other participatory strategies during testing. Capacity building opportunities and exposure of teachers to metacognitive tasks for updating their teaching skills and techniques are tools for improving problem solving and these are strongly recommended.

Educators should consider infusing MP into instruction as a means to foster self-reflective awareness. Educators should adapt methods to change both student self-efficacy beliefs and implement strategies to overcome limitations during testing. Because of the significant ceffects of sefficacy on testing, it is highly recommended that science educators and teachers make a deliberate attempt to assess the existing levels of self-efficacy in students at classroom level and apply appropriate interventions to low self-efficacious sudents should be taken to help raise their self-efficacy levels through vicarious learning, metacognitive prompting, self-regulated learning, goal setting, among others. A longitudinal study may provide more evidence of the influence of metacognitive prompts on test performance. Future research should investigate other variables that influence performance in testing environments besides metacognitive prompting.

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