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STA2017-2276

Effectiveness of Teaching Strategies in Mathematics

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This paper should be cited as follows:

Stojanovski, E. (2017). **"Effectiveness of Teaching Strategies in Mathematics",** Athens: ATINER'S Conference Paper Series, No: **STA2017-2276.**

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8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
URL Conference Papers Series: www.atiner.gr/papers.htm
Printed in Athens, Greece by the Athens Institute for Education and Research.
ISSN: 2241-2891
05/10/2017

Effectiveness of Teaching Strategies in Mathematics

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Abstract

Due to the abundance of data collected at an increasing rate in all fields of society, there is a much greater demand for suitably qualified statisticians and mathematicians to analyse it. This has partially contributed to the recent emphasis on Science, Technology, Engineering and Mathematics (STEM) seen as necessary for Australian education. It has been recognised that students need to study in these areas to be able to properly facilitate scientific developments. The identification of Mathematics as one of the pillars of STEM is the first step required to move closer to achieving this goal. Teaching mathematics and statistics is challenging. Many commencing tertiary students, for example, have negative experiences of statistics and mathematics and many have associated anxieties with regards to these courses, some of which are a result of their experiences with studying these courses at secondary level. There is further concern that the research on teaching and learning statistics remains disconnected. Recent research in statistical education has focused on the need for reform in statistics and mathematics pedagogy and in methods of teaching these courses, which should take into account learning theories. The main traditional learning theories include Behaviourism and Cognitive theory, both of which are associated with learners remaining passive. The more recent focus in mathematics and statistics education has been on constructivist learning theory which has been claimed to be a more effective setting to encourage motivation and interest in learning and, thus, to potentially provide a better opportunity for improved learning outcomes. Evidence of the superiority of this approach as a learning tool is limited. The present study will analyse secondary data to assess whether these different approaches to learning are associated with differing exam performance scores in a secondary school setting.

Keywords: Effectiveness, Learner, Mathematics, Teaching methods.

Introduction

Due to data being collected at an increasing rate, there is an increasing demand for suitably qualified individuals to analyse it. Employers expect employees to have relevant problem solving skills and it is widely recognised that statistics and mathematics are the more important quantitative courses in a university degree (Watson and Sullivan, 2008). This has partially contributed to the recent emphasis on Science, Technology, Engineering and Mathematics (STEM) seen as necessary for Australian education. It has been recognised that students need to study in these areas to be able to properly facilitate scientific developments. The identification of mathematics as one of the pillars of STEM is the first step required to move closer to achieving this goal.

It has been recognised, however, that the study of statistics and mathematics can be challenging. Students have shown inconsistencies in their reasoning about elementary concepts (Groth and Berger, 2006). Service statistics and mathematics courses, for example, often cater to students with varying backgrounds and abilities, many of whom have previous negative experiences with studying statistics and mathematics (Zieffler et al., 2008). Furthermore, some students have associated anxieties about these courses (Stojanovski, 2015). It has also been identified that students of today think and learn differently than students of previous generations (Ertmer and Newby, 2013), suggesting the need to revisit and potentially update traditional teaching practices to promote learning (Stojanovski, 2015).

There has been increased attention recently on teaching and learning aspects of statistics education (Tishkovskaya and Lancaster, 2012). There is a concern that research on the teaching and learning of statistics remains disconnected (Zieffler et al., 2008). Research in statistical education over recent years has focused on the need for reform in statistics pedagogy and in the teaching of statistics (Smith and Staetsky, 2007), which requires an understanding of how students learn.

Learning refers to the acquisition, retainment, and recall of knowledge. Learning theories are principles that explain how learning occurs (Ertmer and Newby, 2013) and the translation of learning theory into teaching practice is an important consideration (Zieffler et al., 2008).

Traditional Learning Theories

Traditional learning theories focus on developing knowledge and skills whereby students learn by absorbing information. In this setting, an instructor's methods are considered effective if they are able to transfer information clearly. The main traditional learning theories include Behaviourism and Cognitive theory whereby the learner remains passive and the teacher is responsible for transferring information directly to learners. Teaching to facilitate this learning theory then focuses on learning occurring as a result of information processing (Mayer and Massa, 2003). Teaching hence focuses on classroom organisation and management particularly on aspects of clarity, structure, discipline and feedback to optimise learning outcomes so that information is easy to process (Walberg and Paik, 2000), while retrieving the information is aided by repetition (Mayer and Massa, 2003). The positive influence of structured classrooms on improved learning outcomes has been reported (Walberg and Paik, 2000). These traditional approaches have strongly influenced teaching for many years whereby learners remain passive and listen to receive knowledge. In addition to secondary schooling, traditional teaching styles have also dominated the classroom for teaching statistics courses at tertiary level for many years.

Behaviourism

Within the Behaviourism learning framework, learning occurs when knowledge is broken up into smaller sections and students are rewarded for correct responses. The focus of teaching is on conditioning the behaviour of learners so that the new behavioural pattern is repeated until it becomes automatic (Schuman, 1996). The teacher is seen to provide the material while the learner receives the information until the behavioural change is permanent. In summary, behaviourism is based on learners being told to do whereby consequences encourage a behaviour, an example of which is studying for a test to achieve a high grade.

Cognitive Theory

The Cognitive learning theory framework involves facilitating and supporting changing of internal thought processes of learners to enable behavioural changes. Students learn best when they practice and perform independently of others. Internal cognitive learning strategies are facilitated by assisting learners to recall prior knowledge and experiences and by identifying types of learning outcomes (memorization, application, problem solving, etc.). The role of the instructor is to assist the application of learning strategies while the learner is active in the learning process. Cognitive leaning teachers view errors as unsuccessful attempts to understand, order and act on their environment in ways that make sense to them. The learner manipulates knowledge and restructures in response to new information and experience (Gordon and Edward, 1994).

Combination of Methods

Most teachers have traits of both the behaviourist and cognitive learning theories. In mathematics, being proficient requires being able to use prior knowledge from one situation to another. In open-ended problems, students need to know which math function to use and how to apply a method to solve the problem. In science, students have some prior knowledge that is often incorrect and the teacher needs to acknowledge misconceptions and design tasks to reformulate knowledge using activities. The nature of the learning task and proficiency level of the learners should both be considered when incorporating these strategies (Anderson et al., 1996).

Limitations of Traditional Theories

While traditional approaches promote independent learning, the student today is different to the student from two or three decades ago. Learners who lack understanding often lose interest within the traditional framework. When many learning theories were developed, few people owned mobile phones (Siemens, 2004). More people today are technologically advanced (Prensky, 2010) and communication is often in the form of multi-media which is also becoming a main driver in learning (Sharples et al., 2006). There are more non-traditional learners, including students commencing tertiary study at differing stages of life, and who thus require varied learning modes (Cantor, 1995).

Constructivist Learning Theory

The constructivist learning theory defines learning as active, constructive and cumulative whereby students develop understanding, building on former knowledge (Shuell, 1996). Unlike the behavioural approach, which restricts learners to be passive recipients of knowledge by listening and reading, active learning is enhanced by social interaction (Cooperstein and Kocevar-Weidinger, 2004) by creating an environment that focuses on exchanging ideas and group work. Teaching focuses on developing understanding and providing opportunities to construct knowledge (Garfield and Ben-Zvi, 2007) and has recently become the new dominant educational theory (Karagiorgi and Symeou, 2005). The teacher's role changes to a facilitator who asks questions and guides students to help them find their own answers with the focus on student-centred learning through active learning activities and problem solving tasks on real world applications to stimulate problem formulation and engagement (Libman, 2010). Research support for constructivist teaching techniques has been mixed, with some research supporting these techniques and other research contradicting them.

Application of Methods to Maths and Science Teaching

In mathematics and science learning, and in statistics education, there has been more of a focus on the constructivist learning theory (Collins et al., 2001). It has been demonstrated, particularly in learning of mathematics and science concepts, that effective learning settings allow students to actively construct knowledge (De Corte et al., 1996) by building on previous conceptions and experiences, hence allowing better engagement with students and further opportunities for learning (Duit and Confrey, 1996).

Incorporating Modern Learning Theory into Teaching of Statistics

There has been a recent reform movement in education, including statistics education, based on constructivism (Tishkovskaya and Lancaster, 2012). It has also been proposed that supplementing strategies from the more recent constructivist learning theory has the potential for increased collaboration in the classroom whereby the instructor's role becomes more of a facilitator to encourage motivation and interest in learning which, in turn, will potentially provide a greater opportunity for improved learning outcomes in the tertiary setting, and consequently a potential increase in the number of students selecting career options with a science or mathematics focus (Stojanovski, 2015). Suggestions were made in a previous paper (Stojanovski, 2015) for strategies to incorporate the constructivist learning theory for the teaching of an undergraduate statistics course by use of real world examples and the incorporation of technology to promote learning. A combination of both approaches was advocated, given the harm that could result from taking the constructivist approach to its extreme. Active based learning student discussions are advocated by asking many questions and by smaller group discussions and use of real world examples. Students work together and build on each other's responses, further enabling possible cognitive conflict to be reduced (Wadsworth, 1996). Technology has become a major part of everyday life and is increasingly being used as a teaching tool to enhance the motivation of learners. For example, the use of interactive hand-held devices, also referred to as clickers, in the previous two deliveries of the course, during lectures, has received positive feedback (Stojanovski, 2015).

Effectiveness in the Secondary School Setting

Evidence of these practices in the secondary setting remains debated. Do elements of constructivist teaching that occur in regular classrooms also have positive effects on students' learning? The present study will analyse secondary data to assess whether these different approaches to learning are associated with differing exam performance scores based on secondary school student data.

Methods

Sample

Data from 14 481 secondary school students participating in the Programme for International Student Assessment (PISA) 2012 study in Australia were analysed. The PISA study assesses performance of 15-year-old school students in reading, mathematics, and science literacy (OECD, 2013). Some of the measures collected as part of the study include math achievement score as well as measures that assess the ability of students to learn in the form of the frequency with which different teaching strategies were used in the classroom (OECD, 2013).

Measures

Questions on the utilisation of each of several teaching strategies in the classroom were administered to students as part of a student questionnaire. A brief description of each teaching strategy that was assessed for the present study follows. These strategies were selected as facilitation one of the three learning theories under study (Behaviourism, Cognitism and Constructivism). Several subscales measured each teaching strategy. In the questionnaire, students rated how often their mathematics teacher incorporated each teaching technique subscale in the classroom with possible answers given on a 4-point likert scale with answers ranging from 1 = *all the time* to 4 = *never*. For the proposed analyses, items were then reverse recoded such that a high score reflects a high degree of utilisation of each teaching strategy. Subscale scores were averaged to produce an overall average score for each teaching strategy.

Two teaching strategies were selected as most reflective of the Behaviourism teaching trait including *Teacher-Directed Instructions*, which measures clarity and understanding of learning goals and was made up of the following subscales: *sets clear goals, encourages thinking and reasoning, checks understanding, summarises previous lessons and informs about teaching goals*. *Maths Teaching* was the other strategy selected as most reflective of the Behaviourism learning theory, which measures teacher interest and provision of additional help, and was made up of the following subscales (*teacher shows interest* and *helps*). Similarly, items were recoded such that a high score reflects a high degree of use in the classroom for each strategy.

The teaching strategy facilitating the Cognitive learning theory was *Cognitive Activation* which was measured in terms of the following subscales: *encourages students to reflect problems, gives problems that require thinking, presents problems with no obvious or multiple solutions, presents problems in different contexts, helps learn from mistakes, asks for explanation, applies what is learnt.*

The teaching strategy *Student Orientation*, which was measured in terms of subscales: *differentiates between students when giving tasks, assigns complex projects, has students work in small groups* and *plans classroom activities* was most reflective of the Constructivism learning strategy.

Mathematics exam performance was measured using a score out of 35 representing the proportion of administered questions that were answered correctly and final scores were standardised. The exam covers various content areas such as conducting routine procedures, applying knowledge, or solving mathematical problems (OECD, 2013).

Statistical Analysis

Variables are used on two different levels in this study with students' math achievement score and the student's perception of the rate of utilisation of teaching strategies were used on the individual student level and the school was used as the class level. The effects of these teaching strategies on mathematics achievement score were assessed and compared using the multilevel regression technique (Raudenbush and Bryk, 2002) which takes into account the hierarchical structure of data with students nested within schools and considers the individual and school level variables simultaneously. This clustered sampling method violates the assumption of independent observations of conventional statistical tests. Students from different school tracks can be expected to vary in their achievement levels, and possibly in other variables

(Baumert et al., 2010). To take these differences into account, the secondary school was included in the analyses.

Results

Multilevel regression modelling was used to assess the bivariate association between each of the assessed teaching strategies and mathematics achievement score, with school as the random factor to account for students being clustered into schools. Results of the bivariate associations using mixed models are presented in Table 1. The two teaching strategies that facilitate the Behaviourism learning theory (*Math teaching* and *Teacher directed Instructions*) were significantly and positively related with math achievement score (b_1=0.036 and b_2=0.029 respectively, p<0.001) indicating that increased use of these teaching strategies were associated with higher math achievement scores, on average. The teaching strategy associated with the Cognitive learning theory was *Cognitive activation* and was also positively and significantly associated with math achievement score (b_3=0.035, p<0.001). As these scales were measured on the same scale, the magnitudes of the regression coefficients were relatively similar in terms of their effect on math achievement score, indicating a relatively consistent positive effect of the traditional styles of teaching on math achievement scores. The final teaching strategy assessed was *Student orientation* which was reflective of the modern Constructivism learning theory. Interestingly, this teaching strategy was significantly and negatively associated with math achievement score (b_4= -0.049, p<0.001) indicating that a greater use of this teaching strategy was aassociated with a significant decline in math achievement scores, on average.

Results of fitting the adjusted multilevel regression model with the incorporation of all teaching strategies simultaneously in the model, to allow for adjustment for other teaching strategies being used in the classroom, are presented in Table 2.

Table 1. *Bivariate Analyses of Teaching Strategy by Math Achievement Score*

Parameter	Estimate	Standard Error	df	t	*p*-value
Maths Teaching	.036	.0029	9051	12.18	<0.001
Teacher Directed Instructions	.029	.0033	8999	8.72	<0.001
Student Orientation	-.049	.0035	9201	-14.02	<0.001
Cognitive Activation	.035	.0034	9015	10.16	<0.001

After adjusting for the other teaching strategies, all strategies remained statistically significant predictors of mathematics achievement score (p<0.0001). The two strategies associated with the Behaviourism teaching strategy (*Maths Teaching* and *Teacher Directed Instructions*) remained positively related with math achievement score, and both with very similar magnitudes of effect (b_1=0.024 and b_2=0.021 respectively) indicating similar effects on math achievement scores. Cognitive activation also remained positively related with math achievement score, with the effect almost double that of the other two teaching strategies that reflect the Behaviourism learning theory (b_3=0.042) suggesting the cognitive strategy to potentially be more effective. The teaching strategy associated with the Constructivism learning theory, *Student orientation*, however, remained negatively and significantly associated with meth achievement scores; the absolute magnitude itself considerably larger than those of the other teaching strategies (b_4=-0.085), although in the opposite direction, suggesting the constructivism learning theory to be potentially substantially detrimental to the learning of mathematics.

Table 2. *Adjusted Multilevel Model of Teaching Strategy by Math Achievement Score*

Parameter	**Estimate**	**Standard Error**	**df**	**t**	***p*-value**
Intercept	.389	.011	8509	33.36	<0.001
Maths Teaching	.024	.004	8938	5.89	<0.001
Teacher Directed Instructions	.021	.005	8872	3.97	<0.001
Student Orientation	-.085	.004	9204	-21.87	<0.001
Cognitive Activation	.042	.005	89173	8.71	<0.001

Conclusions

After adjusting for the other teaching strategies, all strategies remain statistically significant predictors of mathematics achievement score (p<0.0001). The two strategies associated with the Behaviourism teaching strategy (Maths Teaching an Teacher Directed Instructions) remained positively related with math achievement, and both with very similar magnitudes indicating similar effects on math achievement scores. Cognitive activation also remains positively related with math achievement score, with the effect almost double that of the two teaching strategies that reflect the Behabiourism learning theory suggesting the Cognitive strategy to potentially be more effective in terms of math learning. The teaching strategy associated with the Constructivism learning theory, however, remained negatively and significantly associated with meth achievement scores after adjusting for other teaching strategies; the magnitude itself considerably larger than that of the other teaching strategies, suggesting the constructivism learning theory to be potentially substantially detrimental to the learning of mathematics in the secondary classroom.

Motivation of students was not assessed in this study. Approaches that take the interplay of students' learning and motivational processes into account would be recommended for further studies. The present paper draws on learning theories to examine the effects of particular teaching approaches that facilitate the learning theories of behaviourism, cognitism and constructivist, on students' achievement. It is proposed that each of the teaching strategies have an influence on engagement and motivation, which in turn, potentially influence learning outcomes, as was advocated in a previous study (Anderson et al., 1989). Testing of engagement and motivation as mediators on the studied relationship would be recommended for future studies.

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