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Levels of mathematical creativity in model-eliciting activities

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Abstract

The research project aimed at investigating how pre-service teachers could be prepared to use mathematical modelling to develop creativity in young children aged six to nine. As part of the research project these student teachers solved model-eliciting activities (MEAs) to develop and consolidate their own mathematical knowledge, and at the same time develop their creativity and modelling competencies. These experiences of student teachers then served as source of reflection and reference in the development of their knowledge of how children learn mathematics through mathematical modelling in the early school years. Five hundred and one student teachers completed different model-eliciting activities in a longitudinal project over a period of two years. A framework with four criteria for the identification of creativity was successfully used to evaluate levels of creativity in the solutions to the MEAs. The undergraduate students' final models displayed reasonably consistent levels of creativity regarding the four criteria of the framework. Their motivation to solve MEAs and create multiple, original and useful – therefore creative – solutions also increased over the period of their exposure to modelling tasks.

Keywords: model-eliciting activities, mathematical creativity, mathematical modelling

Introduction

Creativity and problem solving are considered crucial building blocks to global and personal success in the 21st century (Marshak 2003; Seo, Lee, & Kim 2005; Sriraman 2005). Florida (Britten 2012) denotes economic success to innovative thinking and states that creativity decreases inequalities and improves the quality of living. Creativity is needed to face an unknown future and education should equip learners for this purpose.

Various authors refer to the importance of creativity in mathematics (Chamberlin & Moon 2005; Ervynck 1991; Piirto 1998; Sternberg 1999; Sriraman 2005). A solid combination of creative, practical and analytical skills serves as a prerequisite for the successful application of mathematics in a variety of real life contexts. The mere regurgitation of mathematical knowledge is inadequate for solving problems in real life situations - this knowledge should be applied in a creative way.

The implication for equity in mathematics education is that all learners should have access to mathematics education that promotes their creativity which would consequently have an impact on their future success. The development of mathematical creativity should not be considered a luxury that is reserved for a specific group of learners and students in South Africa, but should form part of socially responsible education on all levels of education.

Mathematics curricula worldwide stress the importance of mathematical creativity. The purpose statement of mathematics in the curriculum of New South Wales in Australia reads:

> The aim of Mathematics in K–10 is to develop students' mathematical thinking, understanding, competence and confidence in the application of mathematics, their creativity, enjoyment and appreciation of the subject, and their engagement in lifelong learning (Government, New South Wales 2002, p. 7).

The role of creativity in the problem solving process is also mentioned in this curriculum: "Problem solving can promote communication, critical reflection, creativity, analysis, organisation, experimentation, synthesis, generalisation, validation, perseverance, and systematic recording of information" (p. 12). In the United States the Common Core State Standards (CCSSI 2010) refer to the importance of creativity in the analysis of reality-based situations with the focus on models through which these situations are described: "Real-world situations are not organized and labelled for analysis; formulating tractable models, representing such models, and analyzing them is appropriately a creative process. Like every such process, this depends on acquired expertise as well as creativity" (p.72).

In the general aims of the National Curriculum and Assessment Policy for Grades R–12 of the Department of Basic Education in South Africa (DBE 2011:5), creative thinking is listed as a desirable skill to be developed in learners. This curriculum "… aims to produce learners that are able to identify and solve problems and make decisions using critical and creative thinking" (DBE 2011:5). One of the specific goals in the curriculum for the teaching and learning of mathematics for grade 1 to grade 3 is that learners should develop an appreciation for the fact that mathematics is a creative part of human activity (DBE 2011:8). Although the curriculum documents on mathematics for grade 1 to grade 3 give detailed instructions on the content and methods in which teachers are expected to implement the contents, the terms 'creativity' and 'creative thinking' are found nowhere else in the document and no guidelines are given for the development of creative thinking in mathematics.

Various research studies reported on in the literature point out the feasibility and success of a modelling approach in mathematics wherein rich, complex, open tasks are used to construct meaningful mathematical knowledge to prepare learners for everyday life, tertiary studies and their future careers (Biccard 2010; Niss, Blum, & Galbraith 2007; Mousoulides, Sriraman, & Christou 2007; Sriraman 2005). Literature also points out that such model-eliciting tasks can be used as instruments to develop creativity and to identify creative giftedness (Chamberlin & Moon 2005; Fox 2006; Freiman 2006; Lesh 2001).

Creativity in mathematics

Creativity is most commonly associated with the arts, but it is also a fundamental part of mathematics, technology, economy and politics - in truth it forms an integral part of a person's everyday life (Robinson 1999).

Different viewpoints on the definition of creativity exist within the literature and can differ from one culture to another (Seo, Lee & Kim 2005; Sriraman 2005; Sriraman 2004). Many of these definitions specifically refer to the complexity of the construct (Chamberlin & Moon 2005; Fetterly 2010; Sriraman 2004). Some authors take the viewpoint that creativity encompasses domain specific processes through which new representations of a concept are developed, while others strongly oppose this with the view that creativity is brought forth when an individual, a domain and a field coincide (Chamberlin & Moon 2005).

Creativity is also categorised with regards to specific characteristics. Torrance (1974) describes creativity with regards to three components, i.e. fluency, flexibility, and originality. Fluency in the context of mathematical problem posing and solving, refers to the generating or creating of multiple solutions; flexibility refers to a change in focus, direction or approach during problem solving; and originality refers to the level of novelty in the development of new, unique solutions. These components are still used by researchers to identify creativity (Gil, Ben-Zvi & Apel 2008; Leikin & Lev 2007; Silver 1997). The four characteristics of creative processes that are emphasized in the Robinson report (Robinson 1999) connects with Torrance's components: *imaginativeness* in thinking and acting; *purposefulness* in imaginative activities; the creative processes should produce *original* products; and lastly the outcome of the creative process should be *valuable* with regards to the goal. Creativity is therefore defined by Robinson as an imaginative activity that is implemented in a way that the outcomes thereof are original and valuable (p. 30). The definition of creativity by Sternberg and Lubart (2000) focuses on the ability to produce unexpected original work that is applicable and adaptable in the real world and therefore useful.

The fact that creativity is closely related to problem solving in mathematics, and specifically the solving of complex real life problems, is weaved like a golden thread through the literature on the definition of creativity. The importance of mathematical creativity is discussed by various authors (Chamberlin & Moon 2005; Sriraman 2004, 2005; Leikin & Lev 2007) and many of the existing definitions refer specifically to the complexity of the construct (Seo, Lee & Kim 2005; Sriraman 2004). Creative students do not merely regurgitate mathematical knowledge that they have learned when they are solving problems, but use new and unusual strategies in their solutions (Sternberg 1999). Sternberg is of opinion that mathematical analytical reasoning abilities are not necessarily sufficient to solve real-life problems - a solid combination of analytical, practical and creative thinking is also necessary. Chamberlin and Moon (2005) state that students that show an extraordinary ability to create new and useful solutions for complex and simulated real-world problems through mathematical modelling, posess creative mathematical talent.

Sriraman (2005) extends the general definition of creativity to mathematical creativity. His definition of creativity is based on insights from Einstein, Inheld and Kuhn, and it contains elements of both Eastern and Westerns perspectives of the construct. Sriraman describes mathematical creativity as a process that opens doors to new, unusual and insightful outcomes that is generated through solving problems - a viewpoint that is generally supported by Westerners, while the Eastern viewpoint of creativity focuses on the reinterpretation of a known problem from a different angle (Seo, Lee & Kim 2005). The definition of creativity supported by Chamberlin and Moon (2005) refers to the domain specific thinking processes that are used by mathematicians when they are solving non-routine mathematical problems.

Authors such as Haylock (1997), and Wu and Chiou (2008), emphasize the difference between process and product in their definitions of creativity. Mathematical creativity is seen as a thinking process that manifests in three 'products', or otherwise characteristics: *fluency*, *flexibility* and *originality*. *Fluency* can be defined as the number of different correct answers, methods, or new questions that are formulated; *flexibility* as the number of different categories of answers, methods and questions; and *originality* as solutions, methods or questions that are unique and shows insight (Sheffield 2000). Plucker and Beghetto (2004:156) formulate their definition of creativity as '… the interplay between *ability* and *process* by which an individual or *group* produces an *outcome* or *product* that is both *novel and useful* as defined within some *social context'* (emphasis added). This definition includes both the creative process and the creative product.

In the next section mathematical modelling is elaborated on and the connection between modelling and creativity is discussed.

Mathematical modelling

Dossey, McCrone, Giordano and Weir (2002) define modelling as a process through which reality-based situations are represented through the use of mathematics. During this process meaningful mathematics is learned through which reality can be understood, predicted and controlled. The Common Core State Standards in the United States of America define modelling as: "the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions" (CCSSI 2010:72).

In mathematical modelling mathematics is applied to realistic and open problems to create powerful mathematical models that can then be elaborated on, adapted and used in other contexts in a generalised form (Lesh & Doerr 2003; Maass & Gurlitt 2009). Mathematical modelling is therefore an important way to make sense of problem situations in a variety of real-world contexts. During the modelling process, the context is gradually stripped away and the question shaped into a mathematical problem. The mathematical problem is then solved and interpreted in the reality-based context wherein it is set. During modelling learners learn mathematics that is worthwhile and their ability to apply mathematical knowledge is refined (Niss, Blum & Galbraith 2007). During the solving of a complex, real-world problem learners repeatedly move through modelling cycles - often through jumping back and forth between the different stages (Ärlebäck & Bergsten 2010). Each stage is characterised through the multiple cycles of interpretation, representations, explanations, statements and justifications that are repeatedly refined through interaction with other learners (Doerr & English 2001).

The processes of problem solving and modelling in mathematics are closely related. In contrast to a narrow view of problem solving where a single cycle process is used to get the answer to a routine problem, modelling consists of multiple problem solving cycles. In the general aims of the South African Curriculum and Assessment Policy (CAPS) seven aspects are referred to in the prospects of education at school (DBO 2011), i.e.: "identify and solve problems and make decisions using critical and creative thinking; work effectively as individuals and with others as members of a team; organise and manage themselves and their activities responsibly and effectively; collect, analyse, organise and critically evaluate information; communicate effectively using visual, symbolic and/or language skills in various modes; use science and technology effectively and critically showing responsibility towards the environment and the health of others; and demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation (p.5)." These educational aims connect well with mathematical modelling, since all seven of these aspects are combined elements of the modelling perspective.

Modelling is seen as an important way through which learners' mathematical understanding can develop and through which teachers can come to know learners' way of thinking and their problem solving strategies. When a modelling approach is followed in the teaching and learning of mathematics the focus rests on mathematising realistic situations that makes sense to the learner (Wessels 2006). According to Glas (2002) there are various benefits connected to the use of models and modelling in the classroom: learners develop a concept for interconnectedness of topics in mathematics, but also between topics outside of mathematics; develop the realisation that different perspectives of knowledge domains exist; get creative in their mathematical thinking; and learn to see mathematics as practical and applicable in the world they live in.

Complex, reality based tasks, or model-eliciting tasks (MEAs) are used in a mathematical modelling approach. The characteristics of model-eliciting tasks and reasons why it serves as the ideal mode for the development of creativity is subsequently discussed.

Model-eliciting tasks

Model-eliciting tasks (MEAs) are complex, open, non-routine problems in a variety of real-world contexts that can be approached by learners at different entry levels and then solved through the interaction between their informal and more formal mathematical knowledge (Wessels, 2011). These rich, open mathematical tasks enable learners to develop models and elicit creative applied mathematical knowledge (Chamberlin & Moon 2005; Cline 1999; Freiman 2006; English & Watters 2009; Mousoulides, Sriraman & Christou 2007). There are two main reasons why MEAs should be developed and used (English 2003; Lesh, Hoover, Hole, Kelly & Post 2000): firstly, learners are given the opportunity through the modelling of complex mathematical problems to consolidate their existing mathematical knowledge and to build new knowledge. Secondly, teachers are given the opportunity to study learners' mathematical thinking.

The solving of model-eliciting tasks comprises a process of interaction between modelling *competencies* and the modelling *process* during which a *group* product (model) is produced that is *new and useful* in a real-world context (Biccard 2010; Lesh & Doerr 2003; Lesh, Cramer, Doerr, Post & Zawojewski 2003). This description of the process shows a direct resemblance with the description of the creative process mentioned previously. The statement can therefore be made that creativity can be developed through mathematical modelling, and more specific through the solving of MEAs.

A model-eliciting task requires learners or students to develop a model that describes a real-world situation; to revise and refine their ideas and to use representations to explain their ideas and to document it (Lesh, Carmona & Post 2002). A variety of external representations are used to reveal ideas when models are developed. These representations can include graphs, formulas, tables, words, written texts and so forth. Conclusions about the nature of students' mathematical knowledge and the development thereof - including their thinking - can be drawn through studying these representations. MEAs are solved in groups of three to five people. The solution requires a mathematical model that should be useful to the client that is identified in the problem. The students should therefore clearly describe their thinking processes and supply convincing reasons for their solution to make it useful for the client. An MEA does not have only one solution, but the students should try to find the optimal solution for the client and therefore they usually need to change, improve, refine or adapt their first solution.

MEAs therefore offer students the opportunity to mathematise situations through reasoning, communication, justification, revision, refining, and predicting skills when they are engaged in solving problems. These activities help to develop divergent thinking, communication skills, fluency with representations, cognitive flexibility, creativity, and the ability to apply mathematical knowledge. It also promotes teaching and learning with the focus on understanding and cultivates an appreciation for the use of mathematics in a real-life context (Chamberlin & Moon 2005; English 2006).

The use of open problems in a real-world context leads to multiple interpretations and a variety of different solutions. Mann (2006) asserts that the solving these type of problems is a step in the direction of mathematical creativity. The independent solving of complex problems through self-invented strategies promotes the development of intuition and creativity, as well as convergent and divergent thinking (Cotic & Zuljan 2009; Manuel 2009). The ability to plan, evaluate and refine solution paths is also developed through this process. Since MEAs therefore promote *fluency*, *flexibility*, *novelty*, and *usefulness*, these activities can be used as the ideal tool in developing mathematical creativity.

In the past learners with extraordinary abilities and creativity could not easily identify with the narrow and superficial tasks in traditional textbooks and tests. Through the use of MEAs a wider spectrum of abilities and concepts in mathematics, of which the usefulness ranges far beyond the mathematics classroom, can be developed and assessed (Lesh 2001; Lesh & Lehrer 2003).

Research design

This article reports on the development of education students' creativity through solving MEAs and the evaluation of the creativity in their models. This study is part of a larger qualitative, longitudinal study to prepare undergraduate education students to implement mathematical modelling from grade 1 to grade 3 and to develop the creativity of learners through this process. Document and artefact analysis was used as the qualitative research method in this study.

Purpose of the study

The main goal of the investigation described here was to identify levels of creativity in education students' solution strategies to MEAs and to subsequently determine the value of MEAs in the development of creativity. A sub-focus of the study was to test a framework for levels identifying creativity in mathematical models.

Sample and context

Mathematical modelling is included as a subject in the mathematics of education module for Foundation Phase education students in their second, third and fourth year. The participants of the study were therefore five hundred and one prospective teachers in the named groups over two consecutive years (Table 1). Most of the prospective teachers were used to traditional, artificial word problems from school textbooks and were not previously during their school training, exposed to complex, rich, open tasks in mathematics. The MEAs were solved during three to four class periods of 50 minutes each by groups of two to six students each. During the first two years of the study all three year groups of student teachers solved the same MEAs at different times during the year. In the third year of the longitudinal study the year groups completed different MEAs and during the writing of this manuscript the analysis of the solution of the MEAs of the third and fourth year cohorts' models was not completed. Only the results of the second year group for MEA 3 are therefore reported on (Table 1).

Table 1: Number of participants

Year	***N***					
	MEA 1		**MEA 2**		**MEA 3**	
	Students	**Groups**	**Students**	**Groups**	**Students**	**Groups**
2nd	72	22	95	25	85	17
3rd	63	17	71	17	-	-
4th	48	14	67	21	-	-
Total	183	53	233	63	85	17
MEA, model-eliciting task, *N*, total.						

Groups had to submit all calculations and workings for their tasks, as well as their final model and a detailed description of the process that they followed. Each group had the opportunity to explain their solution strategy and modelling process to three or four other groups in a presentation, after which the different solution strategies of all groups were compared in a combined class discussion. In the last phase of the learning trajectory on modelling each group had to create two MEAs for smaller children (aged six to nine). Reporting on this final creative phase of the learning trajectory is done in another article and will therefore not be discussed here.

Measuring instruments

Model-eliciting tasks (MEAs)

Three MEAs in the literature was selected for use over the period of two years:

- **Model-eliciting task 1 (Addendum 1):** “Don’t drink and drive” (Lesh, Hoover & Kelly 1992:126). Data on the blood alcohol level, the amount of drinks consumed, body mass and time elapsed given in table format was given to prospective teachers. They had to develop an instrument that could be used by telephone consultant at a proposed new Call Centre to estimate the blood alcohol concentration of a caller and in doing so determining whether or not (s)he is within legal limit. Students could identify well with this task since they are confronted with difficult choices regarding alcohol use in their social lives at university.

- **Model-eliciting task 2 (Addendum B):** “Making money” (Lesh, Amit & Schorr 1997: 67). An entrepreneur has taken nine vendors into service to sell popcorn and cold drinks at a play park during the summer. Prospective teachers were asked to make recommendations to help her to decide which six vendors she should rehire for the next summer. The decision should be based on their sales and the number of hours they worked during slow, steady and busy shifts. Many students pay for their own studies or earn pocket money through working part time in their free time. This kind of work also often consists of shift work and earning money per hour - they could therefore easily identify with the context of this activity.

- **Model-eliciting activity 3 (Addendum C):** “Olympic Records” (Lesh, Hoover & Kelly 1992:127). Winning times of both men and women in the previous 200m races at the Olympic Games had to be used to predict winning times for the next 50 Olympic Games. This task, selected to coincide with the Olympic Games in 2012, sparked a lively interest amongst students as they could relate well to the context of the activity.

Instrument used for the assessment of creativity

The instrument used to identify levels of creativity is based on the literature discussed earlier in this article. This framework consists of the following four criteria:

- *Fluency* that refers to the generation of different solutions.
- *Flexibility* that entails the change of shift that takes place in the emphasis, direction or approach of creative problem solvers.
- *Novelty* that refers to the level of originality in the development of new and unique solutions.
- *Usefulness* that is grounded on the relevance, adaptability and reusability of solutions in other real world situations.

The first three - *fluency, flexibility* and *novelty* - originate from the work of Torrance (1974), and has recently also been used by Gil, Ben-Zvi and Apel (2008); Leikin and Lev (2007), and Silver (1997). The last criterion - *usefulness* - is derived from the definition of creativity formulated by Sternberg and Lubart (2000) and strongly links creativity to mathematical modelling.

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Data sources

Data sources consist of all the work done by prospective teachers in the modelling of the MEA. This includes all rough and final work such as drafts, tables, graphs, formulas, descriptions and final the final recommendation letter, as well as each group’s description of their problem solving process.

Analysis

The analysis of the models mainly focussed on the four assessment criteria for creativity identified in the literature: *fluency*, *flexibility*, *novelty* or originality, and *usefulness* in reality. A ways of thinking sheet (Chamberlin & Moon 2005) of all different solution strategies (models) for each MEA was compiled. Solution strategies and representations used by each group to document different phases in the modelling process were analysed. Solutions that were based on the same strategy was analysed further and divided into groups to determine the level of sophistication of the models. The levels of creativity for each of the criteria in the framework were classified as low, medium or high based on the number of different solutions of representation (*fluency*); the amount of shifts in emphasis or changes in the direction of approach (*flexibility*); the level of originality (*novelty*) of the model in comparison with models created by other groups; and the level of applicability, adaptability and usefulness of the model in other real-world situations (*usefulness*).

Results and discussion

Creativity in the solution strategies and representations of all the cycles of prospective teachers' models were investigated. Examples of the levels of sophistication and creativity that surfaced in the models in each of the three tasks are given below.

Model-eliciting activity 1: "Don't drink and drive"

Representations play an important role in the modelling process and leave a trail of prospective teachers' thinking as they solve a task. MEA 1 elicited a wide variety of new and unusual representations that include diagrams, tables and different types of graphs. Most of the groups did not create merely one solution to the task. The difference between more or less creative groups is therefore not as evident in the number of different representations (*fluency*) as in the criteria of *flexibility* and *novelty*. The models created by the prospective teachers did not show consistent levels of high or low creativity, measured against all four criteria in the framework. One second year group's model was for example on a high level of *novelty*, but at the same time on a low level for one or more of the other criteria. One group's completely unique bar graph (high level of *novelty*) (Figure 1) was preceded by five different graphs (high level of *flexibility*) (three of these graphs are shown in Figure 2), but it was not suited to the specific situation (low level of *usefulness*).

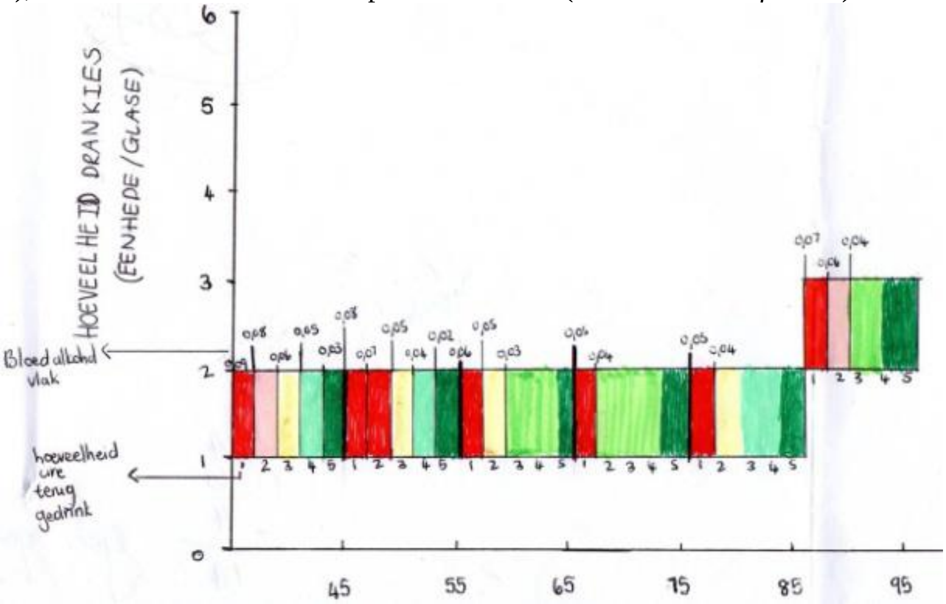

Figure 1: Unusual bar graph produced by Group 1.

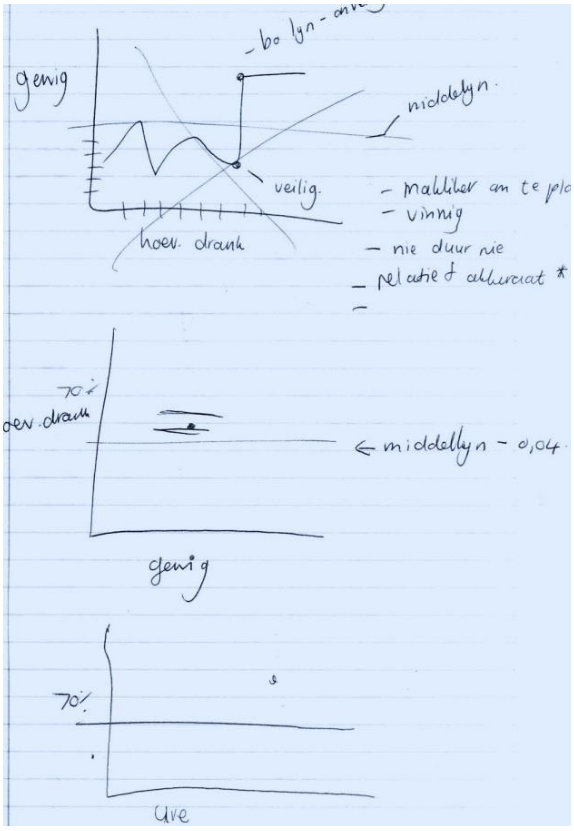

Figure 2: Three of the graphs that preceded Group 1’s final graph (model)

Model-eliciting activity 2: “Making money”

The categorisation of answers clearly shows different levels of *fluency*, *flexibility*, *novelty, and usefulness* (Table 2). Two of the groups’ responses are discussed. Group 1 calculated the total income and the total amount of hours separately, but did not combine the two sets of data. They therefore created a less sophisticated model (*flexibility*) and did not change their approach or direction during the solution process. They did not critically evaluate their solutions and therefore kept their original idea (*fluency*) which led to a less original (*novelty*) and less useful model (*usefulness*). Group 1’s model therefore consequently shows lower levels of creativity when measured against all four criteria in the framework.

In contrast to this, group 43 went through multiple modelling cycles (*fluency*) and changed their approach four times (*flexibility*). Their final model combined the two given sets of data and is based on calculations of income per hour for each vendor separately during slow, steady and busy times. They created a sophisticated model (*flexibility*) to rank all the vendors according to a point system (*novelty*), and in the process they created an adaptable model that could be implemented in other real-world situations (*usefulness*). This group’s model therefore shows consequently high levels of creativity with regards to the four criteria.

Table 2: Analysis of responses

	Category	Description	Number of group responses
No combining of the two data sets	**Total income and total number of hours worked** N=6	Totals only	2
		Totals for different shifts, & rankings	4
	Average income and average	Average hours & average income	1

	number of hours worked N=1		
Combining the two data sets	**Income per hour (R/h)** N=41	R/h for months separately	3
		R/h over 3 months	15
		R/h for different shifts & R/h overall	6
		R/h for different shifts & R/h overall & ranking	4
		R/h for different shifts & R/h overall & ranking using ratio	1
		R/h & consistent high scores for different shifts	1
		R/h & R/h for slow times	1
		R/h & R/h in busy times (for deciding part time vendors)	2
		R/h & weighting (points system)	5
		R/h & % of average R/h of all vendors together	1
		R/h & average of all vendors together – deviation from average	1
		R/h & average of all vendors together – above this average	1
		Total	48

Source: Wessels, 2011

Model-eliciting activity 3: "Olympic Records"

Group 7 initially calculated the difference in winning times of one Olympic Games to the next and tried to look for a pattern in these differences. There was, however, no pattern; they then illustrated the individual winning times graphically and drew a line of best fit for each graph. They then calculated the percentage increase or decrease of the winning times of every four years. The emphasis was then shifted to a 'human ability factor' calculated by using different formulas which they referred to as the percentage decrease in winning times. They therefore calculated the decrease and increase in winning times between Games, the average decrease and increase as well as the tendency of decreases. They came to the conclusion that the decrease in winning times will get smaller to the point where it is negligibly small and it will never be zero. Group 7 therefore worked out multiple solutions (*fluency*) and changed direction or approach many times (*flexibility*). Their original idea to calculate differences between winning times was not only unique in the cohort, but the inclusion of a 'humanness' or 'human ability' factor was also unique in the class (*novelty*). Their calculations were not reliable, but the final model that focused on the 'humanness factor' was *useful*. The creativity that is evident from this group's model (solution) can therefore be classified as medium to high because the model measured relatively high against all the criteria.

The proposed framework could therefore be effectively used to determine levels of creativity in these MEAs.

Implications for the development of creativity through the use of model-eliciting activities

Findings in the study by Seo, Lee and Kim (2005) on educators' concept of creativity point out the fact that educators need a good, well-grounded concept of creativity - including cognitive, personality, and environmental components of creativity - to optimally develop learners' creativity. Educators should in conjunction with a good concept of creativity, be equipped with knowledge and skills to develop creativity through mathematical modelling. They should have knowledge of key principles and concepts of mathematical modelling and should have a positive disposition towards mathematical modelling (Doerr & Lesh 2011; Wessels 2009). They should have suitable beliefs on the nature of mathematics and mathematics education and be aware of their own competency to implement the modelling approach successfully in schools (Maass & Gurlitt 2009). Student teachers should therefore be exposed to mathematical modelling before they enter the practice of teaching.

The traditional approach in classrooms does not promote the development of creativity since knowledge is 'transmitted' from the teacher to the learners, and learners repeat learned rules and procedures as demonstrated by the teacher (Cobb, Wood, Yackel & McNeal 1992). The finding of a single correct answer leads to the decline of learners' own creativity and does not allow space for initiative, thinking and strategies. The way in which learners are educated by the traditional school system endangers their creativity and imagination systematically: 'Education is meant to take us into a future we can't grasp ... yet we are educating our children out of creativity' (Robinson 2008). Fox (2006:223) indicates that learners need to be adaptable, creative and future-orientated mathematical thinkers and problem solvers in order to function in a society that is increasingly based on technology and information. Prospective teachers should therefore be exposed to effective methods for developing creativity, such as the use of powerful problem solving activities through which mathematical knowledge, mathematical skills and creativity are developed. Good model-eliciting activities represent activities that have the potential to develop both mathematical knowledge and creativity. Education students should be properly prepared to develop learners' creativity through the use of MEAs - this, however, implies that their own creativity should be developed first in order to broaden their mathematical knowledge and to form a better understanding of how the process of the development of mathematical creativity in learners should progress.

Through solving model-eliciting activities and the subsequent explanation and justification of their solution strategies during group presentations, as well as through exposure to the process, products (final models), explanations, and reasoning of other groups, student teachers' own mathematical knowledge is developed and consolidated. Through a metacognitive awareness of and reflection on this process they went through, they develop a better understanding of the process learners go through when solving complex real-world problems. The analysis of their own models according to the criteria of creativity thereafter and reflection on the course of their solution processes represents higher order reflective abstraction where actions on one level become the objects of reflection on the next level (Piaget 1985).

When student teachers with reference to their own experience of mathematical modelling reflect on how the processes in the mathematics classroom could progress and how to make sense of children's thinking, their understanding of and teaching competencies in mathematical modelling are developed: "Expertise in teaching involves the development of powerful conceptual tools for making sense of students' work" (Lesh & Lehrer 2003:11). Through going through the modelling process themselves and studying the creativity in their own models student teachers also get a better insight into the role that modelling could play in the construction and consolidation of mathematical knowledge and the development of creativity.

The choice of modelling problems is of crucial importance in the development of creativity. Chamberlin and Moon (2005) emphasise that MEAs specifically focus on the development of creativity and discuss five curricular characteristics of this sort of activity, MEAs that are planned well is firstly interdisciplinary - the primary mathematical content can be applied in a variety of non-mathematical contexts. Secondly, MEAs are also structured well - sufficient information is given in order for the task to be solved. Thirdly, MEAs are realistic problems with which learners can easily identify with and that makes sense to them in their own lives. Fourthly, the solving of MEAs should be steered by the metacognitive coaching of the teacher. The task chosen by the teacher therefore plays an important role to enable learners to reflect on their strategies and to encourage multiple - and therefore creative - strategies. Fifthly, MEAs enable teachers to study the learners' thinking since learners are expected to document their solutions and thinking processes and to give reasons for decisions of the chosen problem solving paths. Chamberlin and Moon (2005) further state that the interdisciplinary nature of MEAs, metacognitive coaching, and problem solving are the three characteristics of MEAs that focus strongly on creativity.

Limitations of the study

The researcher planned interviews with selected groups and to question their solution methods and processes in creating their models. On account of students' academic obligations the researcher could not conduct these interviews within a reasonable time after the completion of the MEAs. Later the students could not describe or remember their problem solving strategies and models, even after studying the written materials. Interview data could therefore not be used at a later stage as it did not generate meaningful data.

Group presentations to the whole class and discussion of solution strategies and processes are valuable in advancing reflective thinking and metacognitive strategies. These class presentations and discussions was possible during the first year of this project, but are no longer viable due to increase in the number of students over the last couple of years. A new model of peer and facilitator assessment through the means of poster presentations in smaller groups is currently being tried out and has presented promising results up to this far.

Concluding remarks

The fact that creativity can be developed through solving MEAs is confirmed through the research that has been described here. Students' willingness to become engaged in the solving of MEAs and to develop multiple, original and useful - therefore creative - solutions increased in the time frame in which they were exposed to modelling tasks.

The proposed framework for the analysis of prospective teachers' models with regards to the four criteria of creativity has proved to be a useful tool to identify creativity in solutions in this research project. The representations in the different modelling cycles did not consistently reveal the four criteria of creativity. Analysis of the levels of reasoning in the final models did, however, more consistently show the four criteria.

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Addenda

Addendum A

An example of model-eliciting activity 1: "Don't drink and drive"

Don't drink and drive

Read the following article about drinking and driving.
Every year, thousands of people are killed in car accidents. Hundreds of thousands more are injured. As many as 50% of car accidents are caused by drunk drivers. The Arrive Alive campaign aims to crack down on drunk driving. Across the country, drunk driving is a very serious crime. There are laws governing how much a person may drink and still be considered safe to drive. Anyone who has a blood alcohol level of 0.05% or higher will be considered drunk and not fit to drive. Persons caught driving drunk can lose their licenses, receive a fine and a possible jail sentence. It is important for those individuals who choose to drink to understand what their blood alcohol level is. The higher the level, the more impaired a person's abilities are. A can of beer, a glass of wine or one shot of hard liquor all contain the same amount of alcohol. Each of these should be counted as one drink. How much an alcoholic drink affects someone depends on the person's weight. So, the effect of a glass of wine is much more pronounced in a slight person than in someone heavy. Once a person stops drinking, the blood alcohol drops about 1.5% per hour. For example: a 64 kg person with a blood alcohol level of 0.10 % would have a blood alcohol level of 0.085% after one hour and 0.070% after another hour. While a person can legally drive at blood alcohol levels of 0.04%, experts warn that impairment is still possible. To be safe, the best policy is never to drink and drive. If one does drink, however, one should at least have a 'designated driver'. This is a person who accompanies other people, but chooses to abstain. At the end of the evening, the designated driver takes everyone home safely. Other ways for drinkers to be safe is to call a taxi or stay overnight at the place where they are drinking. These alternatives seem inconvenient, but being involved in an accident or going to jail is even worse!

Table 1: Blood alcohol concentration % within one hour.

Body Weight (kg)	**Number of drinks**				
	1	**2**	**3**	**4**	**5**
45	0.04	0.09	0.15	0.20	0.25
55	0.03	0.08	0.12	0.16	0.21
65	0.02	0.06	0.10	0.14	0.18
75	0.02	0.05	0.09	0.12	0.15
85	0.02	0.05	0.08	0.10	0.13
95	0.01	0.04	0.07	0.09	0.12

Don't Drink and Drive hotline! A community group wants to start a Don't Drink and Drive Hotline. They have asked your group for help. The group needs a method to estimate a caller's blood alcohol concentration. Develop useful tools for estimating this. You may want to use tables, graphs etc. Your method should work for the wide range of cases the hotline might receive. Write a description of your tools and method to assist the hotline employees that will be applying them.

Addendum B

An example of model-eliciting activity 2: "Making money"
During the last summer holidays Maya started a concession business at Wild Days Amusement Park. Her vendors roam the park with popcorn and drinks for sale. Maya needs help deciding whom to rehire next summer.
Last year Maya had nine vendors. This summer, she is only able to employ six – three full-time and three half-time. She wants to rehire only the most successful vendors, but she doesn't know how to compare them because of unequal shift lengths. Also, ***when*** they worked, makes a big difference. After all, sales would peak on a crowded Friday night and dip on a rainy afternoon. Maya reviewed her records from last year. For each individual vendor, she totalled the number of working hours and the money collected – when business in the park was good (high attendance), steady, and slow (low attendance) (see Table 1 and Table 2). Please evaluate how well the various vendors did for the business last year and choose three she should rehire full-time, and three half-time.

Write a letter to Maya giving your results. In your letter describe how you evaluated the vendors. Give details so Maya can check your work; do give a clear explanation so she can decide whether your method is efficient.

Table 1: Hours worked last summer.

Vendor	November			December			January		
	Busy	Steady	Slow	Busy	Steady	Slow	Busy	Steady	Slow
Maria	12.5	15	9	10	14	17.5	12.5	33.5	35
Kim	5.5	22	15.5	53.5	40	15.5	50	14	23.5
Terry	12	17	14.5	20	25	21.5	19.5	20.5	24.5
Jose	19.5	30.5	34	20	31	14	22	19.5	36
Yusuf	19.5	26	0	36	15.5	27	30	24	4.5
Thandi	13	4.5	12	33.5	37.5	6.5	16	24	16.5
Robin	26.5	43.5	27	67	26	3	41.5	58	5.5
Tony	7.5	16	25	16	45.5	51	7.5	42	84
Willy	0	3	4.5	38	17.5	39	37	22	12

Table 2: Money collected last summer (in Rand).

Vendor	November			December			January		
	Busy	Steady	Slow	Busy	Steady	Slow	Busy	Steady	Slow
Maria	690	780	452	699	758	835	788	1732	1462
Kim	474	874	406	4612	2032	477	4500	834	712
Terry	1047	667	284	1389	804	450	1062	806	491
Jose	1236	1188	765	1584	1668	449	1822	1276	1358
Yusuf	1264	1172	0	2477	681	548	1923	1130	89
Thandi	1115	278	574	2972	2399	231	1322	1594	577
Robin	2253	1702	610	4470	993	75	2754	2327	87
Tony	550	903	928	1296	2360	2610	615	2184	2518
Willy	0	125	64	3073	767	768	3005	1253	253

Addendum C

An example of model-eliciting activity 3: "Olympic records"

Olympic records

The editor of a local newspaper is writing an article called 'The Fast Track'. In the article the levels of speed for women and men in the 200 m event for future Olympics are compared and predicted. The editor needs your help to predict the speed levels for the next 50 Olympics (the next 200 years). Write a report on your predictions and conclusions as the editor would have to explain why predictions were made. Include any tables or charts that may help the editor understand your reasoning.

Olympic results

WOMEN: 200 meter

1928–1936 (not contested)

1948

1. Fanny Blankers-Koen (Hol) 24.4

1952

1. Marjorie Jackson (Aus) 23.7

1956

1. Betty Cuthbert (Aus) 23.4 WR

1960

1. Wilma Rudolph (US) 24.0

1964

1. Edith McGuire (US) 23.0 WR

1968
1. Irena Szwewinska (Pol) 22.5 (A) WR
1972
1. Renate Stecher (EG) 22.40 WR
1976
1. Bärbel Wöckel* (EG) 22.37
1980
1.Bärbel Wöckel (EG) 22.03
1984
1. Valerie Brisco* (US) 21.81
1988
1. Florence Griffith Joyner (US) 21.34 WR
1992
1. Gwen Torrence (US) 21.81
1996
1. Marie-José Pérec (Fra) 22.12
2000
1. Marion Jones (US) 21.84
2004
1. Veronica Campbell (JAM) 22.05
2008
1. Veronica Campbell –Brown (JAM) 21.74
MEN: 200 meter
1896 (not contested)
1900
1. Walter Tewksbury (US) 22.2
1904
1. Archie Hahn (US) 21.6
1908
1. Bob Kerr (Can) 22.6
1912
1. Ralph Craig (US) 21.7
1920
1. Allen Woodring (US) 22.0
1924
1. Jackson Scholz (US) 21.6
1928
1. Percy Williams (Can) 21.8
1932
1. Eddie Tolan (US) 21.2
1936
1. Jesse Owens (US) 20.7
1948
1. Mel Patton (US) 21.1
1952
1. Andy Stanfield (US) 20.7
1956
1. Bobby Morrow (US) 20.6 WR
1960
1. Livio Berruti (ITA) 20.5
1964
1. Henry Carr (US) 20.3
1968
1. Tommie Smith (US) 19.8 (A) WR
1972

1. Valeriy Borzov (SU) 20.00
1976
1. Don Quarrie (Jam) 20.22
1980
1. Pietro Mennea (Ita) 20.19
1984
1. Carl Lewis (US) 19.80
1988
1. Joe DeLoach (US) 19.75
1992
1. Michael Marsh (US) 20.01
1996
1. Michael Johnson (US) 19.32 WR
2000
1. Konstadínos Kedéris (Gre) 20.09
2004
1. Shawn Crawford (US) 19.79
2008
1. Usain Bolt (JAM) 19.30