# Innovative Problem Solving and Students' Mathematics Attitudes[1]

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This paper presents the questionnaire attitudinal data from a project conducted over two terms to investigate the impact of using two meta-cognitive tools, vee diagrams, and reflective stories on some students' mathematical understanding, competence in solving problems and mathematics attitudes. Findings have implications for improving students' mathematics attitudes and thinking and reasoning in mathematics learning and problem solving.

Many Australian educationally disadvantaged (ED) middle years and junior secondary students are at risk of leaving school with poor attitudes towards mathematics and low numeracy competencies at the end of Year 10. As defined by the Department of Education, Employment and Workplace Relations (DEEWR, 2007), educationally disadvantaged students are those at risk of not meeting national benchmarks by the end of compulsory education at Year 10. In New South Wales, Australia, ED students may be identified on the basis of their State English Language and Literacy Assessment (ELLA) and/or School Numeracy Assessment Program (SNAP) Test results. Under the auspices of a federal scheme, a project was funded as a pilot study to specifically provide support to a group of ED students primarily to improve their numeracy and literacy outcomes and secondarily, their attitudes towards mathematics. In accordance with the current *New South Wales Department of Education and Training (NSWDET) Goals and Strategies* (NSWDET, 2008), the project introduced two innovative learning tools that were relevant and engaging to assist the targeted ED students enhance their critical problem solving skills and improve the way they think and feel about interpreting, analysing and solving mathematical tasks. Consequently, the project monitored the impact of the combined innovative usage of two meta-cognitive tools: vee diagrams and reflective stories, on students' abilities to solve mathematical tasks (*problems* or *activities*) and attitudes towards mathematics. Specifically, the utilization of the meta-cognitive tools prompted and assisted students (a) *to understand the task* by identifying the given information and the mathematics involved in terms of concepts and principles and then routinely using this knowledge to determine relevant procedures and plausible solutions, (b) *to devise and implement a plan* by using a vee diagram to *guide* the analysis, present, justify, and illustrate results of conceptual analyses, and (c) *to look back over the solution path* and by using concept lists and prompts, compose reflective stories that were situated in the task. For this project, McLeod's (1992) definition of attitudes was adopted, namely, "affective responses that involve positive or negative feelings of moderate intensity and reasonable stability" (p. 581). McLeod contends that attitudes develop with time and experience and are reasonably stable, so that hardened changes in students' attitudes may have a long-lasting effect.

Using a constructivist theoretical approach, the project examined ways students built on their cognitive structures and developed deep understanding of mathematics as they used vee diagrams and composed reflective stories. Broadly speaking, the constructivist perspective advocates meaningful learning (ML) as learning in which students are actively engaged with the construction of their own meanings and subsequent communication of these meanings variously for public scrutiny (Dewey, 1938, Vygotsky, 1978). Also relevant is Ausubel's cognitive theory (2000), which conceptualises ML as deliberately making connections between new knowledge and existing knowledge resulting in a reorganization of the students' cognitive structures to assimilate and/or accommodate this new experience. Doing so creates meaning for the student, which, according to Gowin's educating theory (1981), if accompanied by a felt-significance of the grasped meaning can lead to further actions and choices by the student. This is when learning takes place, a process also

[1] This project was conducted whilst the author was employed at the University of New England, Armidale, Australia.

In R. Hunter, B. Bicknell, & T. Burgess (Eds.), *Crossing divides: Proceedings of the 32nd annual conference of the Mathematics Education Research Group of Australasia* (Vol. 1). Palmerston North, NZ: MERGA. 

captured by Piaget's (1972) notion of cognitive disequilibrium, where previous knowledge is challenged by unfamiliar or misunderstood experiences and moves towards cognitive equilibrium, as these experiences are reconceptualised and the knowledge has been constructed and accommodated meaningfully and deliberately. However, Gowin's educating theory (1981) is particularly pertinent here as it provides the most relevant theoretical bases for the epistemological vee diagram used in the project. It also makes explicit the importance of the role of "feeling" as part of the process of meaningful learning. Also relevant is Vygotsky's notion of the zone of proximal development (ZPD) as students learn to use the innovative tools initially with support from the researcher and assisting teachers. The V-shaped epistemological vee (see Gowin, 1981) explicates the principles of Gowin's educating theory and a means of guiding the *thinking* and *reflections* involved in *making connections* between the *conceptual structure* of a discipline on one hand, and its *methods of inquiry* on the other, as required for the investigation and analysis of a phenomenon to generate new knowledge claims as answers to some focus questions. To guide the *thinking* and *reasoning* involved in *problem solving*, the original epistemological vee was later modified (Afamasaga-Fuata'i, 2008, 1998, see Appendix A). The vee's left side, the "*Thinking*" side, depicts the philosophy or personal beliefs and theoretical framework driving the investigation/analysis of a phenomenon to answer some focus questions. On the vee's right side, the "*Doing*" side, are the records, methods of transforming the records to generate some answers or new knowledge claims and value claims.

## Methodology

The project used a single-group research design to monitor the impact the usage of vee diagrams and reflective stories had on students' mathematics attitudes and abilities to solve mathematics tasks. On one hand, a pretest-posttest research strategy was used to enable attitudinal data collection at the beginning and end of the project. On the other, an interrupted time series design model was utilized to enable repeated measures of students' mathematical competence on a mathematics test at 3 different points (Wiseman, 1999). Finally, to explore students' developing mathematical understanding and proficiency solving mathematical tasks, their qualitative responses to vee diagram (VD) guiding questions and *Tell Your Own Story* (TYOS) reflective prompts during workshops were collected throughout the project.

A 39-item mathematics test, adapted from the *2006 NSW School Certificate Specimen Test,* was designed in consultation with the mathematics teachers and the project's critical friends. The final test, after pilot testing, consisted of a mixture of short answers and multiple choice questions as is typically used in the NSW School Certificate Examinations (NSWBOS, 2002). An attitude questionnaire was also developed based on a literature review with most items adapted from a questionnaire used by Fadali, Velasquez-Bryant, and Robinson (2004) with engineering, science and mathematics students. After pilot-testing with a group of Year 10 students, test was finalised to 34 items (Appendix B) each with a 5-point Likert scale and one dichotomous item. Approximately forty four (44) workshops throughout Terms 2 and 3, 2007 were offered to a group of Year 10 and Year 7 ED students from three schools, as extra assistance in mathematics. A workshop was held at least once a week over two school terms for each school (A, B and C). The researcher participated in all workshops assisted variously by student teachers (in Schools B and C) and in addition, a school teacher in School A. The sequence of content for the workshops varied and was dependent on the current topic covered in each school, primarily so that workshop tasks complemented and provided additional support to students' normal mathematics classes. Content covered included: indices and exponentiation, financial mathematics (discount, selling and cost prices, profit and loss, wages, hourly rates, tax deductions, gross and net pay), statistics (frequency, column graphs, range, mode, median and mean), probability, geometry (similar triangles) and basic trigonometry (sine, cosine and tangent). Only data from the Year 10 ED students are reported in this paper.

The first workshop focused more on familiarizing students with the VD, its various sections and specific guiding questions and demonstrating how a VD may be completed using a simple mathematical task. A similar approach was also adopted for the TYOS prompts. Vee diagrams were incrementally introduced by providing students with partially completed diagrams (e.g., sections: *Problem, What is the given information?, What are the questions I need to answer?* and *What are the main ideas?)* whilst students completed the rest. Encouraging students to think and reason from task descriptions, they were guided to identify the main ideas, articulate the relevant general rules and identify appropriate methods to generate solutions and answers for the problems' focus questions. To develop students' proficiency with these processes, workshop tasks were often word problems. Working collaboratively in pairs, small groups or individually, students solved mathematical problems and/or conducted activities. Teacher support and semi-structured VDs and TYOS sheets to focus workshop activities, were provided. Students were also invited to bring and/or pose their own problems as challenge tasks for the application of VDs and/or for the others to solve. A group of about 30 eligible Year 10 ED students were selected from three secondary schools in regional Australia. This paper presents only the attitudinal data from the questionnaire and relevant VD prompts.

## Data Coding and Analysis

Response categories for the questionnaire items were scored 1 to 5 in increasingly levels of positive attitudes (variable). These responses were then added across items to give each person a total score to summarise a student's responses to all items. Obtaining a single score for a person implied that the items were intended to measure a single variable, often called a *unidimenisonal variable*. Analyses of questionnaire data were conducted using the Rasch Unidimensional Measurement Model (RUMM) (Rasch, 1980) and the software Quest (Adams & Khoo, 1996). The Rasch Model arises from a fundamental requirement: *that the comparison of two people is independent of which items may be used with the set of items assessing the same variable*. It is considered that the researcher is deliberately developing items that are valid for the purpose and that meet the Rasch requirements (Rasch Analysis, 2005). A Rasch analysis gives a range of details (e.g., infit mean squares [ims] and standardized infit *t* [infit *t*]), which checks whether or not adding the scores is justified in the data. This is called the *test of fit* between the data and the model. The latter is paramount and suggests items are working together consistently to define an interpretable construct. The Rasch analysis also provides separation reliability indices to indicate how well the items and persons worked consistently to produce valid measures of the underlying variable.

Thirty four (34) items in the attitude questionnaire used a 5-point Likert scale with response categories ranging from Very Strongly Agree (1), Strongly Agree (2), Neutral (3), Strongly Disagree (4) to Very Strongly Disagree (5); the corresponding ratings from 1 to 5 were reversed for positively worded items and retained for negatively worded items to reflect an overall increasingly positive attitude from 1 to 5. Responses from the VDs and reflective stories, on the other hand, were analysed qualitatively by collating and recording them in a spreadsheet in preparation for the identification of emerging themes.

## Attitudinal Student Responses

A total of 32 Year 10 students took the pre-questionnaire (pre-Q) from 3 schools while 22 Year 10 students took the post-questionnaire (post-Q) from Schools A and B only. School C's Year 10 students who voluntarily withdrew soon after the project started, did not take the post-Q. Rasch analyses showed the overall fit for both items and persons, on average, was acceptable. An inspection of each item's fit however showed 6 items were outside the acceptable limit; consequently, the 6 misfit items were deleted from further analysis. Subsequent analysis confirmed all ims values were within the acceptable limit, thereby corroborating the fit of the data to the Rasch model. Findings (adequate fit of the data to the model, high person separation index and high Cronbach alpha) collectively indicated all items worked together to define and measure a single underlying construct and the persons who attempted the items performed in expected ways. For example, those with positive attitudes were separated out along the continuum towards the top and those with negative attitudes towards the bottom. The higher post-Q mean case estimate indicated a positive improvement in the cohort's mathematics attitudes but differences were not statistically significant ($p$=0.18). To interpret the construct of "mathematics attitudes", one way is to examine the clustering of items at the top (defining most positive attitudes) and bottom (indicating most negative attitudes) of the logit continuum as shown on variable maps.

In the pre-Q variable map, the most-positive-items indicated very strong disagreement with negative statements (e.g., negative feelings [worry and nervousness], dismissive and general avoidance actions when problem solving) and perceiving "understanding mathematics" as simply memorization of procedures. Further indicating positive attitudes were very strong agreements with positive statements (e.g., mathematics is interesting and enjoyable, and has a creative impact on thinking and feelings). In contrast, in the bottom cluster were item-ratings displaying poor attitudes towards mathematics and indicating very strong agreement with negative statements (e.g., not clearly thinking in mathematics, poor retention of rules, rote-memorisation of procedures, and nervous feelings about mathematics). Poor attitudes were further indicated by strong disagreement with positive statements (about problems solving, learning strategies, and relevance of mathematics and its creative impact on their thinking) with neutral agreement about mathematics' cross-curricular usefulness and its importance for future careers.

By the post-Q, positive attitudes (top item cluster) were still described by 2 of the 9 original items with the rest dropping to decreasingly positive attitude estimates. The new item-members included very strong agreement with positive statements (about their feelings about mathematics; perceptions of dependency on teacher assistance; best strategies for understanding, learning, and solving mathematics problems; and mathematics' cross-curricular usefulness); and very strong disagreement with the negative statement about perceived ability to learn advanced mathematics. In contrast, many of the items which initially described negative attitudes shifted upwards to become more positive. Retained in the bottom cluster were two items on the relevance of mathematics (a) across the curriculum and (b) future career whilst the rest were new members. The latter reflected very strong disagreement with positive statements (e.g., the use of models/diagrams in problem solving and willingness to improve, and enjoyment studying mathematics) with neutral agreement about mathematics' relevance.

Overall, it appeared that positive mathematics attitudes were variously described by strong feelings of liking, interest, enjoyment, intellectual challenge, not worrying and not being nervous when doing mathematics, the promotion of creative thinking and development of flexible methods of solution as calibrated for the pre-Q variable map. In contrast, by the end of the project, positive mathematics attitudes continued to be holistically described by these strong feelings and intellectual challenge and in addition, mathematics becoming a most favourite subject, perceiving teacher assistance (or scaffolding) as a positive requirement, being convinced that best strategies for flexibly solving problems and learning mathematics can result from a conceptual understanding of methods used and that these skills have cross-curricular value. Collectively, these positive descriptors (in terms of thinking, feeling, and acting in mathematics) lent support to their strong belief in their own abilities and potential to learn advanced mathematics. In contrast, poor mathematics attitudes at the beginning of the project appeared described by strong negative feelings (e.g., nervousness, blank minds, and strong dislike) and negative actions (e.g., resorting to memorization strategies in problem solving) and strong disagreement about the perceived usefulness of mathematics for a successful life. By the end of the project, some of these concerns became more positive except for the real-life relevance and mathematics' cross-curricular usefulness. In addition, negative attitudes were newly indicated by disagreements with the role of models/diagrams in problem solving, students' willingness to improve their mathematical understanding, continuing disenchantment with mathematics, and perceived irrelevance in understanding newspaper reports and finance graphs. The potential impact of the innovative strategies on students' attitudes is presented next based on student responses from two relevant VD prompts.

A total of 160 VDs and 160 TYOS sheets were collected from the Year 10 and Year 7 students by the end of the project. Only Year 10 data is presented in this paper. The VD prompt: "*Mathematics is…*", (left-hand side of VD), primarily encouraged students to reflect upon their beliefs and perceptions of mathematics' usefulness either with particular reference to the task they had just completed or in a general sense. Positive responses, indicative of positive attitudes, were further categorised into those reflecting the utilitarian value of mathematics and motivational factors that were affective (e.g., enjoyment, like, and interesting) or cognitive (e.g., understanding, challenging and intellectual stimulation). Negative responses, indicative of negative attitudes, were additionally categorised into those reflecting students' lack of confidence and dislike of the subject, frustration in being shown multiple ways of presenting mathematical ideas and procedures, and reluctant acknowledgement of mathematics' perceived usefulness. Overall, both positive and negative comments provided qualitative evidence, to substantiate the quantitative trends from the questionnaire data in terms of students' perceptions and beliefs about their ability and confidence to do mathematics. Emerging themes from students' responses included mathematics' utilitarian value and motivational factors that were affective (e.g., enjoyment, like, interest) or cognitive (e.g., intellectual challenge, understanding). The VD prompt "*I learnt that…*", (right-hand side of VD), encouraged students to reflect upon the value of their current problem solving experience. Emerging from an analysis of positive responses were categories which collectively reflected a tentative cognitive developmental trend from: *consolidation of existing knowledge*, *making connections to real life experiences, new knowledge and its application-in-context, new methods, intellectual challenge, conceptual understanding, diligence and reward for effort* to *communication of mathematical work*. Responses reflecting negative attitudes were further organised into sub-categories such as: *learnt nothing, too difficult, no value for effort, lack of confidence, one-method one-approach fixation,* and *rote memorisation of procedure*. These sub-categories further substantiated questionnaire findings particularly the descriptors of negative attitudes.

## Discussion and Main Findings

The presented data provided evidence from two sources (i.e., questionnaire and VD prompts) that, initially, students demonstrated it made little sense to put forth effort when their previous mathematics experiences did not always produce results that were considered desirable and positive. Hence, when confronted with VDs and TYOS sheets at the beginning of the project, they felt apprehensive and confused (Stage 1). However, with appropriate teacher support and scaffolding, comprehension and understanding followed (Stage 2) as students learnt about, and adapted, the new strategies to mathematics problem solving. Over time, this understanding matured as students became more proficient and comfortable applying the thinking, reasoning, justification, and reflection that is necessarily part of completing VDs prompts until eventually, they progressed onto the application and consolidation phase (Stage 3). Whilst this evolving, 3-stage developmental proficiency was evident from the findings, students' confidence and competence with the mathematics underpinning the problems and activities fluctuated. It varied, depending on the particular content area (its recency of coverage in their normal mathematics classes including previous successes or otherwise, with it) and type of task. It is at this junction that, the questioning embodied by the VD's guiding questions, served to provide students with a systematic approach (as an alternative, innovative strategy) to unpack the problem statement for the requisite information to complete the different vee sections, facilitated by the teacher initially, with students progressively taking responsibility as they grew more accustomed to the strategies.

**Critical Problem Solving Skills -** Students initially resisted the idea of having to think and reason from task descriptions. Instead, they expected to be explicitly told about the particular method to use, or alternatively, the relevant procedures should be suggested in the problem. For example, students expected to just "do" the problem (i.e., carry out the procedure to get an answer) usually with some external prompting most often from the teacher, but, seemingly, without putting much individual effort into "thinking" and "reasoning" from task descriptions. Apparently, students' previous mathematics experiences had reinforced the mathematical belief, or practice that if they are not immediately able to solve a problem, then typical reactions would be either: "*ask the teacher*" or "*it is difficult ... gay ... or stupid*". This attitude was so entrenched that it took a number of workshops to enculturate students to the notion that with concerted efforts and selfdiscipline, they can develop their own critical problem solving skills to empower them to systematically unpack a problem for the mathematics required and then routinely make explicit connections between their existing patterns of meanings and what needed to be done to solve the problem, all of which required them to actively engage with thinking, reasoning, justification, and reflection.

**Mathematical Reflections and Making Connections -** Over time, findings from VD responses suggested a cognitive developmental trend in the growth of students' know-how about systematically approaching a problem supported by the VD's guiding questions. Specifically, the trend ranged from learning nothing (negative attitude) to include progressively more positive reflections indicating consolidation of existing knowledge, making connections, new knowledge and developing skills in communicating their mathematical understanding more comprehensively and conceptually beyond simply recounting the procedures used in their solutions (positive attitudes). In general, if the problem in learning is conceptualised as: *making connections* between *what is to be learned* (what the learner needs to know) and *what one knows already*, then the evidence presented demonstrated the VD to be a useful epistemological tool to scaffold and facilitate students' cognitive processes of knowing, understanding, justification, and reflection which necessarily formed part of solving mathematics problems, by having them explicitly make connections between their prior knowledge and their critical analysis of given tasks. By revisiting and reconsidering their existing knowledge, comprehending potential relevance and subsequently making explicit connections to the given task, students identified and displayed the necessary prior knowledge and associated methods of solution on vee diagrams. Active engagement with these dialectical processes over time can, and did, empower students to be more convinced of the suitability of selected methods and the plausibility of their solutions particularly *after* substantively justifying methods with relevant general rules and definitions. Evidence of this change in students' attitudes towards flexibly solving problems, best strategies for learning and meaningful problem solving through a conceptual understanding of the main ideas underpinning methods and procedures were; (a) quantitatively demonstrated by the increasingly more positive item estimates of the respective items by the post-questionnaire, (b) subsequent positive shifts of item locations towards the top-item cluster of the variable map, and (c) qualitatively substantiated by students' responses to VD prompts. For most students, despite their negative experiences (both current and past), they openly expressed a need to understand and learn more about mathematics either because of future career aspirations or as intellectual challenges. When their problem solving experiences were positive, successful and intellectually satisfying, they wanted to learn more. Unfortunately, this can quickly change when they continuously encountered difficulties which they felt were not satisfactorily addressed in their mathematics classes. Also some students may have become bored with completing VDs once or twice a week during workshops. Even seemingly novel pedagogical approaches may become tedious when employed repeatedly as Bragg (2007) also found when using games to introduce basic mathematics concepts to primary students.

**Entrenched Negative Mathematics Attitudes & Teacher Involvement** - The withdrawal of one school's Year 10 ED students demonstrated that, for some ED students, attempting to reverse their negative attitudes towards mathematics at Year 10 in a short-term project may be too late. Instead, the needs of ED students should be redressed much earlier. Realities facing school teachers in real schools prevented two school teachers to participate in the workshops although all workshops were held during normal school hours. Ideally, the participation of school teachers in innovative projects would be desirable for sustainability of the innovation beyond the project. However, numerous contextual factors can be and were practical impediments to this participation.

These project findings contribute to knowledge and practice of successful strategies that can improve educationally disadvantaged students' numeracy and mathematics literacy outcomes in any Australian school.

## Implications of Key Findings

The usefulness of vee diagrams as an epistemological tool for thinking, reasoning, justification and reflection should be made more explicit to students. Allowing students to communicate the benefits of vee diagrams in problem solving could draw students' attention to the potential of vee diagrams to systematically guide their thinking, reasoning, justification, reflection and communication during and after problem solving. Students appreciate and enjoy solving mathematics problems that provide them with a positive learning experience and feeling of significance that they have understood the new meaning; therefore teachers should explicitly encourage students to think, reason, make connections to their existing knowledge, reflect on their learning and communicate their new meanings during and after problem solving experiences. Teacher-led discussions which draw out the educational value of thinking, reasoning, justification, and reflection would be useful in promoting a more comprehensive and conceptual view of doing mathematics and hence more positive attitudes towards mathematics. Teachers should be encouraged to support the use of vee diagrams and reflective prompts in the classroom to support students' thinking, reasoning, justification, reflection and communication of their mathematical learning.

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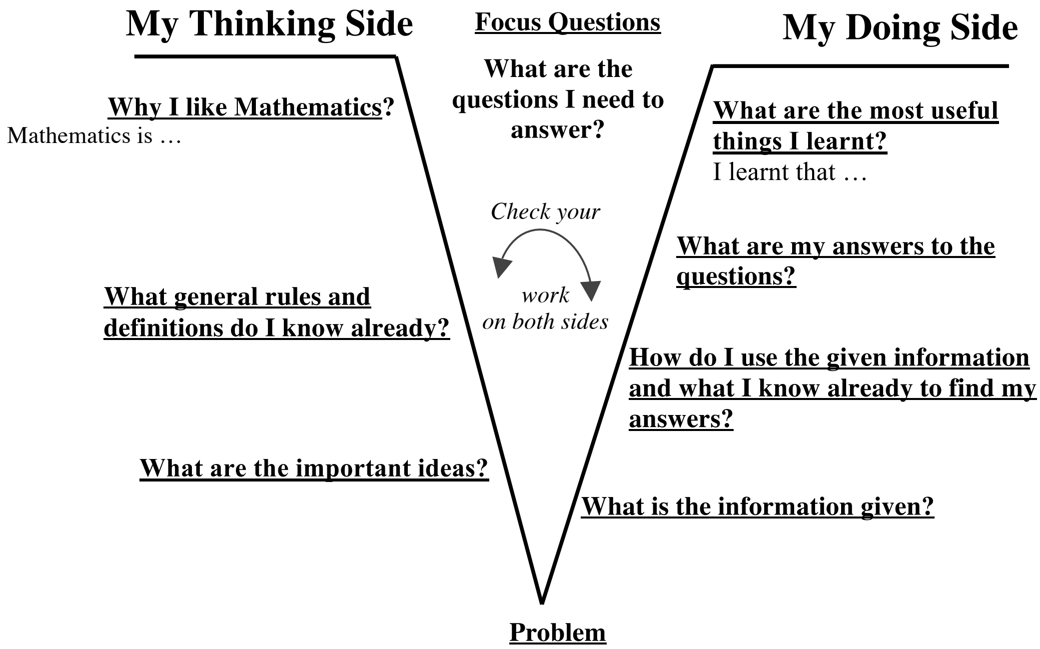
**Appendix A: Mathematics Problem Solving Vee Diagrams**




## Appendix B: Mathematics Attitude Questionnaire

1. Mathematics is very interesting to me and I enjoy my mathematics classes.
2. When doing mathematics, my mind goes blank, and I am not able to think clearly.
3. I like solving mathematics problems.
4. Mathematics makes me feel uncomfortable and impatient.
5. I have always enjoyed studying mathematics in school.
6. I am nervous in mathematics classes because I feel I cannot do mathematics.
7. It makes me nervous to even think about having solving a mathematics problem.
8. I really like mathematics; it's enjoyable.
9. I can cope with a new problem because I am good in mathematics.
10. I get worried when solving a problem that is different from the ones done in class.
11. I can find many different ways of solving a particular mathematics problem.
12. Most of the time, I need help from the teacher before I can solve a problem.
13. I believe that if I use what I know already, I can solve any mathematics problem.
14. I have forgotten many of the mathematical concepts that I have learnt in previous mathematics classes.
15. I learn mathematics by understanding the main ideas, not by memorizing the rules and steps in a procedure.
16. If I cannot solve a mathematics problem, I just ignore it.
17. Successfully solving a problem on my own provides satisfaction similar to winning a game.
18. I feel nervous when doing mathematics.
19. My most favourite subject is mathematics.
20. Mathematics classes provide the opportunity to learn skills that are useful in daily living.
21. To succeed in school, you don't need to be good in mathematics.
22. Mathematics is not my strength and I avoid it whenever I can.
23. I don't think I could learn advanced mathematics, even if I really tried.
24. Doing mathematics encourages me to think creatively.
25. I learn to think more clearly in mathematics if I make a model or draw diagrams of the problem.
26. Mathematics is important for most jobs and careers.
27. Solving mathematics problems helps me learn to think and reason better.
28. To succeed in life you need to be able to do mathematics.
29. Mathematics is needed in understanding newspaper reports and finance graphs.
30. Communicating with other students helps me have a better attitude towards mathematics.
31. I am interested and willing to improve my understanding of mathematics.
32. The skills I learn in mathematics will help me in other subjects at school.
33. I do not have to understand mathematics, I simply memorise the steps to solve a problem.
34. I learn mathematics well if I understand the reasons behind the methods used.
35. I intend to continue taking mathematics next year.