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Is Problem Solving and Systems Thinking Related? A Case Study in a Malaysian University

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ABSTRACT

Does systems thinking facilitate the acquisition of important skills in solving ill-defined problems? This exploratory study seeks to investigate whether an association exists between problem-solving and informal systems-thinking skills. A survey methodology that included a paper and pencil test was used to gather data. Four performance tasks designed and adapted to local context were employed to measure both sets of skills. Following that, the performance of each respondent was scored based on an analytical scoring rubric. Both descriptive and inferential data analysis involving comparisons of the populations and checking for correlations were carried out. Findings indicated that the respondents performed poorly in all the tasks. The mean score for systems thinking was found to be lower than that of problem solving. These skills were analysed according to three pre-selected demographics. Interestingly, the data indicated that there was a positive but moderate association between problem-solving and systems-thinking skills. The limitations and some general recommendations for future research were also discussed.

Keywords: academic achievement, gender, higher education, problem solving, systems thinking

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INTRODUCTION

Education systems throughout the world in the last decade has come under intense scrutiny where its' outcomes are doubted to commensurate with the billions of dollars expended (Reilly, 2000; Senge, 1998; Finn & Ravitch, 1996; Forrester, 1994; Morrison, 1991). As pointed out by Johnson

& Duffett (2003), "For five consecutive years between 1998 and 2002, majorities of employers and professors have been reporting profound dissatisfaction with the skills of recent public school graduates" (p. 20). The education systems is said to fall short of producing workforce that is capable of dealing with today's society which is characterized as dynamic, uncertain and complex.

Realizing this discrepancy, educators have since been emphasizing the teaching for problem solving as a major educational objective (Mayer, 2002). Problem solving is stipulated explicitly in the educational objectives, blueprints, planning, strategies outlined by educational institutions worldwide in their endeavour to produce quality workforce for the society. The main focus of our education curriculum has been learning how to solve problems. However, the traditional approach to problem solving referred as reductionist approach fails to perform well on complex, ill-defined problems and 'when parts of a more complex problem are all independently optimized' (Douglas, Middleton, Antony & Coleman, 2009). This dominant problem-solving approach is said to work better for simple and well-defined problems. Ultimately some systemic theories and models were developed in response to this issue. One approach that particularly stands out from the rest is the systems-thinking approach (Flood, 1999). Systems-thinking approach is not just about how to analyse a situation from the disciplinary perspective but how to synthesize the ideas gained from different disciplines of study to form a better and more holistic understanding that can lead to effective and long lasting actions (Kay & Foster, 1999).

In an effort to identify and promote the 21st century skills, the Partnership for 21st Century Skills Organization, P21 (2011) has put forward a Framework for 21st Century Learning where critical thinking and problem solving are emphasized as important learning and innovation skills every learner should master to succeed in work and life in today's society. While elaborating the elements that constitute successful critical thinking and problem solving, this framework explicitly suggests the use of systems thinking as one of the approaches in solving problems. It is clearly stated by the framework that systems thinking enable one to "analyze how parts of a whole interact with each other to produce overall outcomes in complex systems" (p. 4).

Systems thinkers consider systems-thinking approach as highly relevant in problem solving and decision making in a world that exhibits characteristics of interconnectedness, uncertainties and complexities (Bellinger, 2004; Haines, 2000; Senge, 1990; Kauffman, 1990). Studies have also conclusively shown the advantages of using systems approach to enhance problem solving especially non-routine and poorly defined problems which to many are especially difficult and require multi-skills to solve them (Resnick & Wilensky, 1998; Resnick, 1996). Wilensky (1996) commented that one of the more promising prospects is by integrating the system approach in all problem-solving activities.

Systemic approach that refers to systems thinking is regarded as one of the main approaches to problem solving (Douglas *et al.*, 2009). They viewed positively this approach as one that helps to understand problems holistically and is able to address many weaknesses of the reductionist approach. Goh and Xie (2004) had suggested the incorporation of systemic approach in problem solving to enhance the ability to tackle more complex and dynamic situations.

Problems should be regarded as systems. Components that form these systems could be identified. The interrelatedness of these components could then be analysed. Subsequently problems observed in the interrelatedness of these components are identified and tackled. In contrast to traditional problem solving, systems thinking as a systemic approach has the advantage over traditional problem solving in terms of the effort spent in understanding the interrelatedness, complexity and wholeness (big picture) of components of systems and the specific relationships to one another (Banathy & Jenlink (2004) as cited in Johnson, 2008).

Introducing systems-thinking skills into the activities of problem solving is believed to have some effects on the task of solving problem (Resnick & Wilensky, 1998; Resnick, 1996; Wilensky, 1996). Unfortunately, literature on the assessment of the effectiveness of systems-thinking skills in problem solving is scarce (Maani & Maharaj, 2004; Sweeney & Sterman, 2000; Klieme & Maichle, 1991, 1994 as cited in Ossimitz, 1997; Ossimitz, 1997).

> Many claims have been made concerning the ability of systems thinking interventions to change the nature and quality of thought about complex systems. Yet, despite the increasing number of interventions being conducted in both educational and corporate settings, important questions about the relationship between systems thinking and basic cognitive processes such as problem solving, decision makes, remain unanswered. (Doyle, 1997, p. 253)

A study was carried out to look at the relationship between problem solving and systems thinking. For that purpose, two different scoring rubrics were constructed to quantify problem-solving and systems-thinking skills. This paper focuses on the findings related to the overall problem-solving and systems-thinking skills of the population of interest as well as the influences of three demographics factors– gender, program of study and academic performance. It also reports the association between problem-solving and systems–thinking skills.

PROBLEM SOLVING

The definition of problem solving owes its' origin to the work of Dewey (1910).

He had presented the analysis of an act of thought that relates problem solving as a felt difficulty where the problem solver needs to analyse the situation and makes suggestions of possible hypotheses of which the problem solver then acts on them and carries out an experiment to determine whether to accept or reject the solution. The central notion of problem solving is the goal, either explicitly or implicitly stated in the problem, where not knowing how to reach this goal without generating new information is what makes it a problem (Jonassen, 2002). One interesting phenomenon one can observe in the problem-solving models offered by the experts of the field is that the activity of problem solving is never a top-down or bottom-up or linear kind of task. This view is clearly put forth by Fernandez, Hadaway and Wilson (1994), in their interpretation of the problem-solving processes (see Fig.1).

Many studies into problem solving have focused on how different characteristics of learners from different socioeconomic backgrounds, preferences, and ability levels, in particular their academic performance and grade level, technology courses, mathematics and science grades, gender, personality preferences, and problem solving styles affect their problem-solving abilities (Custer, Valesey & Burke, 2001).

Gender-related differences in ability to solve mathematics problem, specifically, and in problem solving generally, is an actively researched topic and these studies produced mixed results. Some studies have found statistically significant gender-related differences in mathematics ability, especially in solving general (routine) type of problem, in favour of female (Lau, Hwa, Lau, & Limok, 2003; Mason, 2003; Zambo & Follman, 1993). In his study, Mason (2003) found that females, more than males, excel in problem solving because they believe in the importance of understanding why a particular procedure or algorithm works and not only relying on memorization for problem solving. Therefore, the former is not only less likely to fail but is also able to attained better grades than the later. Custer *et al*. (2001) on the other hand found that generally gender does not influence problem-solving skills.

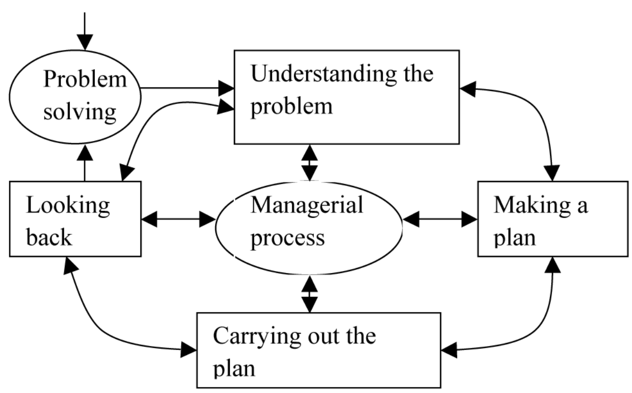

Fig.1: Problem-solving processes (Fernandez *et al*., 1994)

Another factor of interest to problem-solving researchers concerns the question of the relationship between academic performance of the learner and problem-solving skills. Bay (2000) concluded that teaching problem solving and teaching via problem solving improve students' problem solving, skills, and concepts. It is no doubt that when problem solving is emphasized, the learners show improvement in their achievement. However, he was doubtful about the true nature of this relationship. Logically, the learner with good academic performance is always assumed and perceived by others, to be good at problem solving. However, research has shown that learners who perform well academically are not necessarily good problem solvers. Studies show that learners, who are reported as the best or bright students in mathematics, are unable to solve unfamiliar, be it the non-routine or routine, problems correctly and successfully (Lau *et al*., 2003; Davis, 1987; Schoenfeld, 1985).

SYSTEMS THINKING

Richmond (1993) had discussed seven basic systems-thinking skills. He (1997a) later classified them as 1) dynamic thinking which helps one to see behaviour that unfolds over time and deduce behaviour pattern rather than focus on events; 2) system-as-cause thinking which helps one to view system's behaviour pattern as the result of interrelatedness of elements within the system; 3) forest thinking that " … gives us the ability to rise above functional silos and view the system of relationships that link the component parts" (Richmond, 1997c, p. 6); 4) operational thinking that helps ones to identify how behaviour is generated and not merely in terms of 'cause and affect'; 5) closed-loop thinking which enables one to be aware that an 'effect' usually feeds back to change one or more of the 'causes', and the 'causes' themselves will have effects on each other; 6) quantitative thinking that helps one to quantify what is thought to be difficult to measure accurately but contribute a lot to the success or failure of a system; and 7) scientific thinking that is used to make sure that the model developed is able to play its expected role for the purpose of improving its performance (Richmond, 2000). These seven skills have, since then, served as the 'operational' guide to systems thinking. Richmond (1997a) stressed emphatically that the numbering and the sequencing of the seven thinking skills reflects the notion that each skill builds on the previous one.

As hypothesized, performance in systems thinking can be influenced by the demographic characteristics of the respondents. Research on gender-related issues in the study of systems thinking is rather scarce. A study by Ossimitz (2002) was carried out to determine gender-related influence on the respondents' ability to discern between stocks and flows, a crucial systems-thinking skill. He reported that females scored significantly poorer than the males in this respect. Another study by Sweeney and Sterman (2000) was carried out on subjects where most of them were enrolled in post-graduate programs. They intended to assess particular systems-thinking concepts and the demographic variables on their performance scores. Their findings showed some marginal gender effect with the males performing slightly better than the females on all their performance tasks although they reiterated that the effect was only marginally significant.

Sweeney and Sterman (2000) also reported that when their subjects' academic background on the performance tasks were taken into account, some of the questions in those tasks showed significant differences though no consistent pattern could be detected. The subjects' academic background in terms of their prior academic field and highest prior degree was significant and marginally significant for one of their performance tasks. The subjects with technical backgrounds were found to do better than those in the Social Sciences and Humanities in this particular task. The effect of the program of studies in which their subjects were presently enrolled was not significant in any of the tasks. To quote Sweeney and Sterman (2000), "The results provide only limited support for the hypothesis that prior training in the sciences helps performance. It is possible that there simply is insufficient variation in the subject pool to detect any effects" (p. 278).

RELATIONSHIP BETWEEN SYSTEMS THINKING AND PROBLEM SOLVING

It is possible to integrate problem-solving and systems-thinking skills as traditional problem solving activities already exhibit systems-thinking characteristics (Gigerenzer, Todd, & ABC Research Group, 1999; Frensch & Funke, 1995; Richmond, 1993). Many researchers are convinced that instruction in the setting of problem solving with the integration of systems thinking does facilitate the cultivations of important thinking skills (Microworlds Inc. Brochure, 1997 as cited in Sweeney & Sterman, 2000). Systems thinking is said to be a more scientific problem-solving approach than the rational thinking approach (Shibata, 1998). Furthermore, he stressed that systems thinking is a very clear and useful method to solve problems.

Maani and Maharaj (2004) mentioned that there exists one apparent characteristic amongst good and poor performers of the respondents in their research. The good performer reflects the characteristics of systems thinking while those that do not perform well often exhibit the behaviour of linear thinking, the direct opposite of systems thinking. Richmond (1997b) referred to this counterpart of systems thinking as linear thinking or static thinking. This is supported by Dörner (1980) whose study found out that most people would not bother to seriously consider the existent trends and developmental tendencies of complex tasks in advance to solving them; in contrast, they are more interested in the 'status quo'. This explains the scarcity of systems-thinking trait in the traditional thinking of people who subscribe to linear thinking. Hence, it is not surprising that any individual, who displays the attributes of system thinking, even though they are ignorant to systems thinking, do perform better on complex decision-making task (Maani & Maharaj, 2004). The behaviour of the more superior performers reflects the attributes of systems thinking. Maani and Maharaj (2004) concluded in their research that systems thinking when blended with the problem-solving strategies, "manifests the characteristics of heuristics competence, as it involves understanding of the system structure, developing strategies, making decisions and carefully assessing the outcomes" (p. 45). This result strongly indicates that systems thinking is highly correlated with problem solving.

METHODOLOGY

The following section describes participants, instruments and procedures involved in this study.

Participants

The population of this study consisted of all undergraduates of eleven diploma programs of studies in one of the campuses of a Malaysian public university. The respondents were categorized according to programs of studies, gender and their academic performance. To strengthen the university academic programs among faculties and within the faculty, this public university has grouped the students into three main categories of programs of studies, namely, Science and Technology, Business and Management, and Social Sciences and Humanities. The eleven diploma programs of studies identified for this study consisted of six programs from the category of Science and Technology (Diploma in Science, Diploma in Computer Science, Diploma in Sports Science and Recreation, Diploma in Civil Engineering, Diploma in Electrical Engineering and Diploma in Estate Management), four programs from the category of Business and Management (Diploma in Banking, Diploma in Business Studies, Diploma in Office Management and Diploma in Accounting) and one program from the category of Social Sciences and Humanities (Diploma in Public Administration). For the academic performance, the respondents were grouped, based on their cumulative grade point aggregate (CGPA), as Poor (CGPA 2.00 – 2.49), Average (CGPA 2.50 – 3.49) and Good (CGPA 3.50 – 4.00).

Proportionate stratified sampling design was employed to select a sample size of 233 out of a total of 524 students. From the total number of respondents from each program, 20% was selected from the Good group, 60% from the Average group and 20% from the Poor group and where possible, equal numbers of male and female representatives were selected from each group. Simple random sampling technique was then used to select the respondents after the numbers from each group based on gender and CGPA were determined.

Instrument

The initial instrument had six performance tasks, namely The Water Jug Problem (Task 1), Achilles' Challenge (Task 2), The Hilu Tribe (Task 3), Causal Loop Diagram (Task 4), The Alps Hotel Tourists (Task 5) and The Federal Budget of Fantasia (Task

6) to elicit eight systems-thinking skills: wholistic thinking, continuum thinking, thinking in models, leverage point thinking, structural thinking, closed-loop thinking, systems-as-cause thinking and dynamic thinking. This initial instrument was first validated using student focus group and then lecturer focus group. Changes made to the performance tasks based on the feedback obtained from both of the focus groups include taking out Task 1 as this was more for categorizing problem-solving styles instead of systems-thinking skills, taking out Task 2 as almost all of the focus group members were not able to solve it, customizing Task 6 to Family Monthly Expenditure which was more applicable to respondents from different categories of program of studies, reducing eight systems-thinking skills to five, namely dynamic thinking skill, system-as-cause thinking skills, forest thinking skill, operational skill and closed-loop thinking skill, as there were too many sub-skills involved, re-adjusting time given to answer the performance tasks and increasing clarity of instruction given to answer the performance tasks.

The revised instrument was later sent to two external experts in the field for validation. They were Professor Dr. Kambiz Maani from the University of Auckland, New Zealand and Associate Professor Dr. Guenther Ossimitz from the University of Klangenfurt, Austria. Maani (communication through email, 2004) commented that the instrument developed was good at gauging systems-thinking skills and the performance tasks developed were interesting and innovative and represented a good set of systems-thinking questions. Ossimitz (communication through email, 2004) advised the researchers to take out the Causal loop diagram task because this performance task was based only on causal loop diagrams and did not take into account the difference between stocks and flows and therefore would be subjected to more debate and argument. Ossimitz further suggested that some of the questions be rephrased. These comments were taken into considerations and the instrument was then finalized and used in this study.

This instrument consisted of one set of questions which was divided into two parts. Part A consisted of six questions to gather demographic information whereas Part B consisted of five questions. The first question in Part B was to test the respondents' understanding in graphs as the ability to understand graphs correctly could suggest the proficiency of problem-solving and systems-thinking skills of a respondent. The other four questions were the performance tasks used to determine the problem-solving and systems-thinking skills of the respondents. The four performance tasks namely Graphs of Behaviour over Time, The Hilu Tribe, The Alps Hotel Resort and Family Monthly Expenditure, adapted from the works of Ossimitz (2002) and Robertson (2001) were used to elicit the problem-solving and systems-thinking skills from the respondents. (Please refer to Appendix 1 for an example of performance task.)

PROCEDURES

Scoring of problem-solving skills

Assessing cognitive processes is a complicated and difficult task. It is not easily measured through tests, quizzes, or teacher observation. Assessing the outcomes from well-designed performance tasks would be a simpler and more objective alternative. This approach has found support with Mcguire (2001). Many versions of the problem-solving model are proposed to suit the different contexts and environments where it is applied (Fernandez *et al*., 1994; Holton, 1993; Artzt & Armour-Thomas, 1992; Evans, 1992; D'Zurilla & Goldfried, 1971; Simon, 1960; Dewey, 1910). Thus, the approach to measuring problem-solving skills can range from simple but less effective method to highly complex techniques.

This study chose to use a simple but less comprehensive measurement of the problem-solving skills. The rationale here was that since systems-thinking skills at this moment could only be assessed with a simple point-allocated scoring rubric, then problem solving should be gauged using the same level of assessment so that the comparison between the two skills is meaningful. Following this line of argument, a simple point-allocated scoring rubric was created to measure the problem-solving skills of the respondents.

Scoring of systems-thinking skills

The framework for measuring systems thinking in this research was based mainly on the literature review of the works of Richmond (1997a, 1997b & 1997c), Ossimitz (2002) and Maani and Maharaj (2004). The focus here was on the first five of the seven essential systems-thinking skills. The last two skills are more relevant to system dynamics modelling efforts (Maani & Maharaj, 2004). Each of these essential systems-thinking skills was then divided into sub-skills. Skills and sub-skills were carefully worded in the explicit form to reduce subjectivity on the part of the evaluators. These were reviewed by an expert with extensive knowledge of systems thinking. With the guidance afforded by this framework, the construction of a scoring rubric or marking scheme was then constructed.

An analytic rubric was used here as the categories of skills and sub-skills that were to be graded were clear-cut. The sub-skills of the five essential systems-thinking skills were carefully worded for all the four performance tasks. For each correct sub-skill, a certain point was given to it. This point-allocated sub-skill was found to be very useful in determining whether specific criteria had been met for each of the systems-thinking skills in each performance task. (Please refer to Appendix 2 for the systems-thinking skills and sub-skills mentioned here.)

Pilot survey

Thirty students from eleven diploma programs were selected to answer the performance tasks for the pilot survey. The pilot survey was carried out to evaluate the suitability of the instrument and also the effectiveness of the procedures. The students were given one hour and 45 minutes to answer all questions in Part A and Part B. From the result of the pilot survey, some amendments were made to the questionnaire which include taking out CGPA score of 0.00 – 1.99 because there were too few students falling under this category. The time allowed to answer the questions was then reduced to 1 hour 20 minutes as this duration was found sufficient for the students to answer all of the questions.

Data collection

The data was collected through two paper-and-pencil test sessions. Respondents who could not make it for the first session came for the second session. The respondents were gathered in a lecture theatre to answer both sets of questions. The respondents were given one hour 20 minutes to complete the questions in Part A and Part B. A total of 237 students turned up for the actual survey. The first session was attended by 160 students whereas the second session was attended

TABLE 1
Comparing statistical significance between problem-solving scores and systems-thinking scores

	Mean Score		95% Confidential Interval of Mean		Standard Deviation		Statistical test result	
	Problem-solving skills	Systems-thinking skills	Problem-solving skills	Systems-thinking skills	Problem-solving skills	Systems-thinking skills	Problem-solving skills	Systems-thinking skills
Gender								
Male (n = 103)	26.26	23.65	24.06-28.45	21.74-25.56	11.21	9.77	t = -0.684, p = 0.495	t = 0.202, p = 0.840
Female (n = 130)	27.22	23.41	25.43-29.02	22.02-24.80	10.35	8.02		
Program of studies								
Science and Technology (n = 82)	28.92	25.87	26.53-31.32	23.98-27.76	10.88	8.59		
Social sciences and humanities (n = 29)	26.16	22.23	22.32-30.00	19.13-25.33	10.10	8.14	F = 2.543, p = 0.081	F = 4.500, p = 0.012*
Business management (n = 121)	25.52	22.31	23.60-27.44	20.71-23.91	10.66	8.86		
Academic achievements (CGPA)								
2.00 – 2.49 (n = 45)	23.43	21.24	20.36-26.50	18.62-23.86	10.22	8.72		
2.50 – 3.49 (n = 156)	26.72	23.29	25.10-28.34	21.92-24.66	10.25	8.65	F = 6.096, p = 0.003*	F = 5.554, p = 0.004*
3.50 – 4.00 (n = 32)	31.90	27.81	27.58-36.21	24.74-30.89	11.97	8.52		

by 77 students. Four sets of answers were discarded due to missing values.

RESULTS AND DISCUSSION

The following section reports the findings of this study regarding the problem-solving skills and the systems-thinking skills exhibited by the respondents and the relationship between these two skills.

Problem-solving Skills and Systems-thinking Skills

Data collected was keyed-in by the researchers. Exploratory data analysis was subsequently run to detect errors in the keying-in process as well as observe for outliers. The mean scores were calculated for the different categories of skills based on the three selected demographic factors.

The average score for each set of skills was calculated using the arithmetic mean. In the analysis, each respondent was awarded two scores – one for problem solving and another one for systems thinking. Take for example in deriving the mean score of problem solving for the male cohort, an average score of 26.20 was calculated based on a sample of 103 male respondents. The same calculation was carried out for the system thinking scores. The table below contains the mean scores based on the three demographic factors.

Mean scores of problem-solving skills between groups based on gender, program of studies and Cumulative Grade Points Aggregate (CGPA) (academic performance) scores

As presented in Table 1, the performance of the female respondents in solving the performance tasks was slightly better than the male respondents. Nevertheless, this difference was not statistically significant (t = -0.684, p = 0.495).

Among the various programs of studies, it was found that the respondents from Science and Technology programs had the highest mean score (28.9%) followed by respondents from Social Sciences and Humanities program (26.2%) and respondents from the Business and Management programs (25.5%). After considering all the assumptions, the ANOVA analysis showed that there was no statistically significant difference in the mean score for problem-solving skills (F = 2.543, p = 0.081).

When academic performance background of the respondents was taken into account, the result showed that the performance of the respondents with higher CGPA were better than those in the lower CGPA. The respondents with CGPA 3.50-4.00 reported the highest mean score (31.9%) followed by those with CGPA 2.50-3.49 (26.7%) and CGPA 2.00-2.49 (23.4%). Further analysis using ANOVA showed that there exist a statistically significant difference in their problem-solving skills mean score (F = 6.096, p = 0.003). Due to unequal sample sizes of these three CGPA groups, Scheffé post-hoc test was then carried out. It was found that there was no statistically significant difference in the mean scores obtained by respondents with CGPA 2.00-2.49 and 2.50-3.49. However, there exist statistically significant difference in the mean scores obtained by respondents with CGPA 2.00-2.49 and CGPA 3.50-4.00.

Mean scores of systems-thinking skills between groups based on gender, program of studies and Cumulative Grade Points Aggregate (CGPA) (academic performance) scores

As presented in Table 1, the mean scores for systems-thinking skills of the female respondents (23.6%) did not show much difference with their counterpart (23.4%). This was further proven by the *t*-test result which showed that there was no statistically significant difference between the means scores obtained ($t = 0.202$, $p = 0.840$).

When the program of studies of the respondents was used as the basis for comparison, the result showed that the respondents for the programs of Science and Technology scored the highest (25.9%). The mean scores of systems-thinking skills obtained by respondents for the programs of Social Sciences and Humanities and programs of Business Management were similar – 22.2% and 22.3% respectively.

After considering the normality of the data set and the homogeneity of variances ($p = 0.879$), the ANOVA analysis showed that there was a statistically significant difference in the mean scores obtained ($F = 4.500$, $p = 0.012$). Further analysis using Scheffé post-hoc test found that there was a statistically significant difference between the mean scores of systems-thinking skills for respondents from the Science and Technology programs and the respondents from the Business Management programs.

When the academic performance in terms of CGPA of the respondents was used as the basis for comparisons, the result showed that respondents with higher CGPA were able to obtain better scores. The respondents with CGPA 3.50-4.00 obtained mean scores of 27.8%, whereas the mean scores for respondents with CGPA 2.50-3.49 and CGPA 2.00-2.49 were 23.3% and 21.2% respectively.

After verifying the normality and homogeneity of variance for the data set, analysis using one way ANOVA showed that there was a statistically significant difference between the mean scores obtained by respondents with different CGPA ($F = 5.554$, $p = 0.004$). Further analysis using Scheffé post-hoc test found that there was a statistically significant difference between the mean scores obtained by respondents with CGPA 2.00-2.50 and those with CGPA 3.50-4.00. Similarly, the difference was also statistically significant for those with CGPA 2.50-3.49 and CGPA 3.50-4.00. However, the test showed no statistically significant difference between mean scores of respondents with CGPA 2.00-2.49 and CGPA 2.50-3.49.

RELATIONSHIP BETWEEN PROBLEM-SOLVING SKILLS AND SYSTEMS-THINKING SKILLS EXHIBITED

The scatter plot in Fig.2 clearly depicts a linear, positive and moderately strong

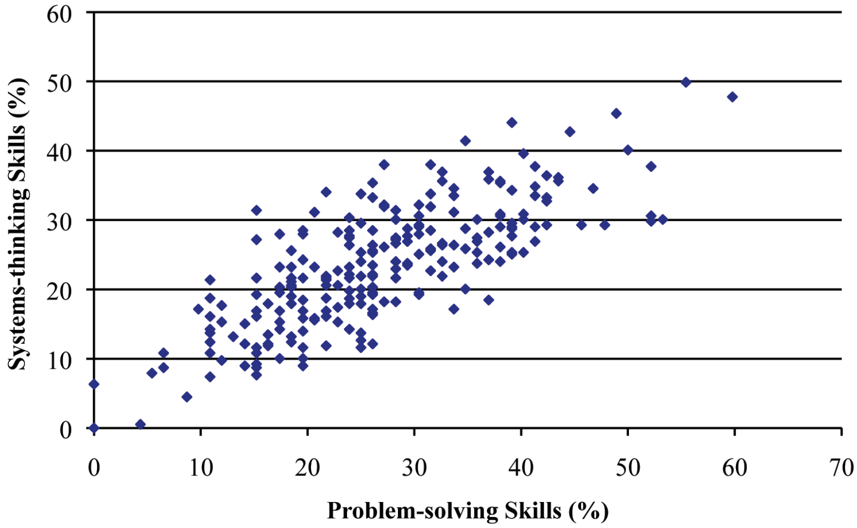

Fig.2: Scatter plot of scores for problem-solving skills and systems-thinking skills

correlation. The result was supported by the Pearson Product Moment Correlation, with $r = 0.776$ and $p = 0.0001$. This implies that if the respondents have good problem-solving skills, they also have good systems-thinking skills and vice versa.

CONCLUSION

One major area of concern in our present education system is the students' problem-solving ability (Robertson, 2001; Schoenfeld, 1999; Resnick, 1996; Duncker, 1945). Problem solving, a generic employability skill, is an indispensable skill one must possess to function effectively in the workplace. To facilitate the acquisition of this skill, it is hypothesized that systems thinking can play a leading role in the attainment of this potentially invaluable ability. This study aimed to determine if such an association exists between problem solving and systems thinking.

Findings from the study indicated that the targeted population of diploma students performed poorly for both problem solving and systems thinking in the four performance tasks. The mean score for systems-thinking skills was found to be lower than that of problem solving. The low mean scores were expected as the four performance tasks were non-routine problems and the structure of the tasks were new to the respondents.

In addition, analyses were performed to determine if the three selected demographic factors affected the skills studied. It was found that problem solving was not affected by gender and program of studies whereas CGPA did influence problem solving ability. On the other hand, systems-thinking skills showed no dependency with respect to gender but systems-thinking skills were affected by program of studies and CGPA. The influence of these factors on both systems thinking and problem solving is inconclusive as similar results were reported in other studies attempting to determine whether gender, academic achievement and program of studies influences the acquisition of these skills (Lau *et al*., 2003; Mason, 2003; Custer *et al*., 2001; Bay 2000; Ossimitz, 1997; Zambo & Follman, 1993; Davis, 1987; Schoenfeld, 1985).

This study also identified an association between problem solving and systems-thinking skills with a Pearson Product Moment Correlation of 0.776. This index implies that those who exhibited good problem-solving skills, also possessed good system-thinking skills.

This finding should be of major interest to the education fraternity at large because this study actually found evidence to support the contention that systems thinking is associated with problem solving. This link has been espoused by many systems thinkers but no empirical evidence was given to support their claims (Maani & Maharaj, 2004; Resnick & Wilensky, 1998; Doyle, 1997; Resnick, 1996; Wilensky, 1996). The significance of this finding lies in exploring new approaches to the teaching of problem solving in the classroom. As Jonassen (2002) explained a problem solver faces obstacles when he/she fail to generate new information from the information at hand. A good systems thinker on the other hand has an array of skills that promotes the use of information in its varied forms to generate new information that can assist him/her to overcome the obstacles mentioned above.

This study has one clear limitation, that is, no causal relationship could be determined using the present research design. In other words, the exact nature of the relationship between problem-solving skills and systems-thinking skills was not determined. Once this fact is established, only then can we move on to look at a paradigm shift by situating a meaningful and successful problem-solving learning environment within a systems-thinking framework. Although this study had not addressed the objectives comprehensively, it certainly is a good start in the right direction towards determining a causal relationship between problem solving and systems thinking. There is much work to be done in exploring further the nature, impact and efficacy of systems thinking in solving non-routine, knowledge-lean and complex problems.

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APPENDIX 1
EXAMPLES OF PERFORMANCE TASKS AND SYSTEMS-THINKING SKILLS

Graphs of Behaviour over Time

Direction: The graphs below illustrate the behaviour of a certain population over a period of time. These behaviours are described in the stories found in the answer booklet. Firstly, match the stories with the appropriate graphs. In addition, label the **x-axis** and the **y-axis** of the graphs in the space provided. For example the x-axis in the graph below stands for "time", you could label the x-axis as "year" or "month" depending on the story. If you **do not understand** the graphs , write "**don't know**".

Match the stories with the graphs given.

2.1 The Story :

The Giant Tortoises of the Galapagos Islands live for well over 100 years. A female can lay 4-5 batches per season, usually between June and December. The eggs hatch 4-5 months later. A group of botanists was studying the population growth for 2 years. Assuming there is no death for the whole duration of the study, which graph accurately shows the population growth of these tortoises?

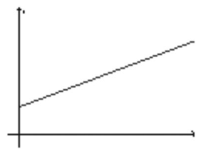
ANSWER:
GRAPH ___________________
x-axis : ___________________
y-axis : ___________________

2.2 The Story:

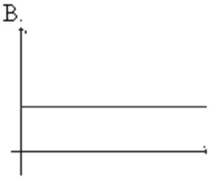
THE ELEPHANTS OF AFRICA live in vastly varying environments of the continent, from the rain forests of the Congo Basin to the savannahs of Namibia. On one occasion, a viral infection spread rapidly among a group of African elephants. The virus caused a rapidly progressing and severe disease which finally results in death of the animal within weeks. Assuming there is no birth during the period of infection, which graph shows what happened to the population of this group of elephants?

ANSWER:
GRAPH ___________________
x-axis : ___________________
y-axis : ___________________

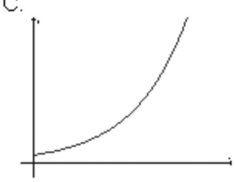
A.



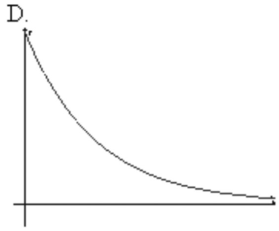
B.



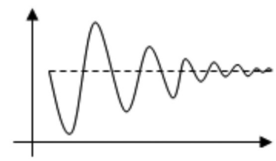
C.



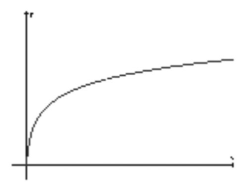
D.



E.



F.



APPENDIX 2
LIST OF SYSTEMS-THINKING SKILLS AND SUB-SKILLS

Systems-thinking Skill	Sub-skills
a. Dynamic	See changes over time as being non-linear. To be aware of stock and flow variables. To understand and be aware of time delays. Able to use the correct time units (in min / hour / day / month / year). To see time continuities within the web of interdependencies.
b. System-as-cause	To identify the boundary of the system under study. To identify which variables are completely/partially under control. To determine the possible explanations for the behavior identified.
c. Forest	To see the links that connect the different elements of the system. To identify the causal links that may exist between its members. To determine the ‘breadth’ and ‘depth’ of the system’s boundary. To identify new properties emerging from the interactions of its components. To filter through all the variables and keeping only the most essentials. To identify what structures/ infrastructures that are causing the behavior. To seach for similarities in a ‘heap’ of elements that might be seemingly unrelated and distinct.
d. Operational	To determine how behavior is generated through interdependency. To identify causality and not only correlation/ influence. To identify the stock and flow infrastructures. To maintain units of measure integrity in a system.
e. Closed-Loop	To link the different variables of interest to form feedback loops. To be aware of both intended and unintended consequences.