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Systems-Thinking Skills Exhibited by UiTM Sarawak Diploma Students in Solving Non-routine Problems

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ABSTRACT

It is hypothesized that systems thinking can play a leading role in facilitating the attainment of important problem-solving skills especially in the context of solving ill-defined problems involving uncertainties and dynamic complexities. As part of an initial effort to determine if there is any basis for saying so, this exploratory study seeks to investigate the systems-thinking skills that are exhibited by two hundred thirty-three UiTM Sarawak Diploma students in solving non-routine problems. Moreover, it also aims to investigate the influence of three demographic factors, that is, gender, Gugusan and Cumulative Grade Point Average (CGPA) on systems-thinking skills. A framework for categorizing systems-thinking skills was developed to measure these aforementioned skills as the respondents solved four non-routine problems. This study used the survey research design to gather data through a paper-and-pencil test and questionnaire. Four performance tasks were used to measure these skills. Following that, the performance of each respondent was calculated based on an analytical scoring rubric for the identified systems-thinking skills. Both descriptive and inferential data analysis were carried out. Findings indicated that the respondents score poorly in systems-thinking performance. The mean score for systems thinking was found to be only 11.76

out of a possible 50. With regard to the three preselected demographic factors, it was found that systems-thinking skills show no dependency with respect to gender (t = .202, P > .05) but was found to be dependent upon Gugusan (F = 4.500, P < .05) and CGPA (F = 5.554, P < .05). The limitations of this study were also discussed. The findings have implications of great importance in the teaching of systems thinking to students. The study ended with some suggestions for future research.

Keywords: *systems thinking, non-routine, performance tasks*

Introduction

The education system throughout the world in the last decade has been rightly questioned by many for its failures to deliver what it was supposed to so to commensurate with the billions of dollars that are spent annually (Reily, 2000; Senge, 1998; Finn & Ravitch, 1996; Forrester, 1994; Morrison, 1991). It has so far failed to meet today's needs in producing a workforce that can deal effectively with uncertainties and complexities. This paper argues for an about turn in its approach to deal with these new challenges in a global environment that requires all of us to move out of our comfort zone. Consequently attention ought to focus on a totally different paradigm. This paradigm should seek understanding through seeing the interrelatedness of the different components in our education system and its emergent properties resulting from the interactions of its part while at the same time not forgetting the dynamic nature of the system that by itself continuously changed and evolved (Sweeney & Sterman, 2000; Reily, 2000; Senge, 1998; Richmond, 1993; Forrester, 1990). One approach that particularly stands out from the rest is the systems-thinking paradigm (Flood, 1999).

Non-routine problems are problems with uncertainties and dynamic complexities by nature. Solving these problems requires a particular set of higher-order thinking. At the same time, to think systemically one has to possess a cache of higher-order thinking skills. Therefore, it is logical to hypothesize that an association may exist between a person's ability to solve problems of this kind and systems-thinking skills possessed. This study thus explores into the systems-thinking skills that may be exhibited by UiTM Sarawak Diploma students in solving non-routine problems. Towards the end, this study aims to measure these skills and subsequently look into the influence of three preselected demographic factors, gender, Gugusan and CGPA scores, on the systems-thinking scores.

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Literature Review

Systems Thinking

Systems thinking have three dimensions: paradigm, language, and methodology (Maani & Cavana, 2000). The main emphasis in this study is on the paradigm aspect as well as the related thinking process within the framework of this paradigm. This powerful and radical perspective enables one to see the events and patterns in our daily lives in a new light and respond to them appropriately.

Seeing the big picture – forest versus trees – is the central notion of systems thinking. The ability to rise above the details and view the whole is very important as mankind has suffered much due to their lack of holistic thinking. This narrow specialization thinking tends to misinform one self into making decision that has very serious consequences (Mulej et al., 2003). As system-as-cause is an 'active' principle that underlies the systemic theory and practice, all systems thinker knows very well that the root causes of a 'problem' have to be identified before a lasting solution can be found (Anderson & Johnson, 1997). Moreover, there is always more than a single cause for a given problem. This multiple causality principle in systems thinking contradicts the linear or 'single-cause' or 'either-or' thinking that has permeated our society for generations.

Comprehending the systems thinking paradigm, thinking process, and methodology remain one of the toughest tasks one can ever engage in (Richmond, 2000). To that end, Richmond (2000) suggests a series of seven different cognitive processes to be mastered. These 'prescribed' thinking skills provide one with the big picture and guideline to master systems-thinking skills for applying them later in real-life situations (Richmond, 2000). Later he developed seven essential skills which according to him would help one to acquire the 'thinking' in systems thinking. Below is a short discussion of these skills.

The Seven Essential Skills of Systems Thinking

Richmond (1993) discusses seven basic systems-thinking skills in his article, Systems Thinking: Critical Thinking Skills for the 1990's and Beyond in which he (1997a) classified as: dynamic thinking, system-as-cause thinking, forest thinking, operational thinking, closed-loop thinking, quantitative thinking and scientific thinking. These seven skills have, since then, provided general guide to the understanding, teaching and learning of systems thinking. Richmond (1997a) stresses emphatically that the numbering and the sequencing of the seven thinking skills reflects the notion that each skill builds on the previous one.

Dynamic thinking helps one to see behaviour that unfolds over time and deduce behaviour pattern rather than focuses on events. System-as-cause

thinking enables the viewing of system's behaviour pattern identified earlier as the result of interrelatedness of elements within the system. Forest thinking " …gives us the ability to rise above functional silos and view the system of relationships that link the component parts" (Richmond, 1997d, p. 6). Operational thinking refers to thinking causally and going beyond this by identifying how behaviour is generated, and not merely in terms of 'cause and effect'.

The closed-loop thinking is important for one to be aware that an 'effect' usually feed back to change one or more of the 'causes', and the 'causes' they will have effects on each other. The sixth skill, quantitative thinking, basically enables one to quantify what is thought to be difficult to measure accurately but contribute a lot to the success or failure of a system. The highest in the series of the seven essential skills is scientific thinking which is particularly useful after one has constructed a model. It is used to make sure that the model developed is able to play its expected role in building a better, shared understanding of a system for the purpose of improving its performance (Richmond, 2000). Systems thinking is said to be superior to other approaches in dealing with complexity (Richmond, 1993).

Literature has also shown that certain demographic factors are related to acquisition of systems-thinking skills of the respondent. So, this study intends to look into the possible influence of demographic factors like gender, program of studies and academic performance on systems-thinking skills.

In this research, it is hypothesized that the 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) suggested 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. Though the context of the performance tasks of these two studies might be different, they share the same structure and thus measuring the same skills.

Sweeney and Sterman (2000) reported that when the effect of their respondents' highest prior degree and major field on the performance tasks was taken into account, some of the questions in those tasks showed significant differences though no consistent pattern could be detected. Prior academic field is significant for one of their performance tasks, and highest prior degree is marginally significant, and, as what they expected, those with technical backgrounds did better than those in the Social Sciences and Humanities in this particular task. The same could not be said of the other tasks. The effect of the program of studies the respondents were enrolled in was not significant in any of the tasks. Subsequent to this, how systems-thinking skills are measured is the focus of the next section.

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Development of Framework for Measuring Systems-thinking Skills

The framework used in this research is based mainly on the literature review of the works of Richmond (1997), Ossimitz (2002) and Maani and Maharaj (2004). The focus here is on the first five of the seven essential systems-thinking skills, e.g. dynamic thinking, system-as-cause thinking, forest thinking, operational thinking and closed-loop thinking. The last two skills are more relevant to system dynamics modeling efforts (Maani & Maharaj, 2004).

The systems-thinking skills framework follows the sequence as described earlier. The sequence of these five interdependent thinking skills is important and their effect is cumulative (Richmond, 1997a; Maani & Maharaj, 2004). With the identification of these dimensions, a scoring rubric is then constructed carefully based on all the sub-skills of the five systems-thinking skills that could be explicitly measured. It is used to measure the systems-thinking skills as exhibited by the targeted respondents in this research. Moskal (2000) defines a scoring rubric as a descriptive marking scheme that has been developed according to the needs of the evaluator to guide his/her analysis of the product or process of a person's effort. A scoring rubric when used in tandem with a checklist for each category of skills can further increase the reliability of the scores because a checklist, in particular, a point-allocated checklist, could assist in determining whether specific criteria have been met.

Non-routine Problems

Problems that contain all the information needed to solve them are categorized as well-defined problems. This kind of problem describes the problem as it stands now (the initial state), what the situation should be when the problem is solved (the goal state), exactly what actions have to be taken to solve it (the operators) as well as actions that and what are not allowed (the operator restrictions) (Robertson, 2001). An ill-defined problem is one where operators and restrictions are not given.

To conclude, in a world that is uncertain and dynamic, problems that are ill-defined or non-routine are by no means simple. They are systemic, dynamic and complex. To meet the needs of the world in such a climate, the paradigm shift to systems-thinking paradigm is inevitable. Systems thinking provides a more global approach that result in more accuracy when describing and analyzing complex problems (Streveler, 2003). It is highly relevant in solving non-routine problem and making decision in a world that exhibits characteristics of interconnectedness, uncertainties and complexities (Bellinger, 2004; Haines, 1998; Senge, 1990; Kauffman, 1990; Houghton, 1989). Thus, the performance task developed in this study may serve as an assessment tool to measure the systems-thinking skills of respondents. By knowing the level of one's systems-

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thinking skills, well-planned efforts may be taken to promote systems-thinking skills among our learners directly or indirectly.

Methodology

Population and Sample

The population of this study was the Part 5 and Part 6 students for the semester of November 2004 – April 2005 from eleven diploma programs in UiTM Sarawak. This group of subjects was considered suitable for this survey because they had been in the UiTM system for over 2 years.

The respondents were categorized according to Gugusan, gender and their Cumulative Grade Point Average (CGPA). For the academic performance, the respondents were grouped as Poor, Average and Good based on there CGPA (See Table 1).

Table 1: Academic Performance Classification According to CGPA

CGPA	Grade	Group
2.00 – 2.49	C, C+,	Poor
2.50 – 3.49	B-, B, B+	Average
3.50 – 4.00	A-, A, A+	Good

Disproportionate stratified sampling design was employed to select a sample size of 233 out of a total of 524 students.

Instrument

The instruments used in this survey consisted of a set of performance tasks for the respondents to answer and scoring rubric to evaluate the respondents' systems-thinking skills.

Performance Tasks

Four performance tasks namely Hilu Tribe, Alps Hotel, Causal Loop and Family Budget were used to elicit the systems-thinking skills from the respondents. These tasks are non-routine in nature. Three tasks were chosen after going through a validation process by using both the student and lecturer focus group. In addition, advices from external systems thinking experts from Austria and New Zealand were also sought to determine the appropriateness of the tasks.

The instrument comprised 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 and the rest of the questions were the performance tasks used to determine the systems-thinking skills of the respondents.

Scoring of Systems-thinking Skills

A framework for measuring systems-thinking skills was first developed based on the systems-thinking skills defined by Manni and Maharaj (2004) and Richmond (2000) to determine the types of systems-thinking skills possessed by the respondents in solving non-routine problems. There were five systems-thinking skills in the framework, that is, Dynamic Thinking Skill, System-As-Cause Thinking Skill, Forest Thinking Skill, Operational Skill and Closed-loop Thinking Skill.

A scoring rubric based on the systems-thinking framework was then developed by the researchers because there was no 'prescribed' marking scheme for measuring systems-thinking skills available in the market. An analytic rubric was used as the categories of skills that were to be graded were clear-cut. Each systems-thinking skill was subdivided into sub-skills. The checklists or sub-skills of the five essential systems-thinking skills were then carefully worded for all the four performance tasks. Hence, for each correct sub-skill, a certain point was given to it.

Data Collection

The data was collected through two paper-and-pencil test sessions. The second session was conducted for those who could not make it for the first session. The respondents were gathered in a lecture theatre and were given 1 hour 20 minutes to complete all questions.

Data Analysis

Descriptive Statistics such as frequency, percentages and graphs such as pie charts and bar charts were used to describe the respondents' profile i.e. gender, Gugusan and CGPA. Mean scores and standard deviation were used to analyse the respondents' systems-thinking skills according to gender, Gugusan and CGPA. Chi-square tests, normality test, test of homogeneity of variances, Independent t-test, ANOVA, post-hoc test and inter-item correlation matrix were employed to make inferences about the characteristics of population based on the sample data.

Findings and Discussions

In this section, the discussion begins with a brief description of demographic characteristics of the respondents which are gender, Gugusan and CGPA. Subsequently, the study will focuses on the system-thinking skills among the respondents according to their demographic characteristics.

Demographic Characteristics of the Respondents

From the total of 233 respondents, 103 (44.21%) are male and 130 (55.79%) female. Almost half of the respondents (52%) were from Business and Management, more than one third were from the Science and Technology (35%), and the rest of the respondents (13%) were students from Social Sciences and Humanities.

67% of the respondents in this study were students with CGPA 2.50 – 3.49, while, minority of the respondents were students with CGPA 3.50 – 4.00 and students with CGPA 2.00 – 2.49 which comprised only 14% and 19%. This is reflective of a nearly normal distribution.

Systems-Thinking Skills Among the Respondents

The analysis of the 233 respondents' systems-thinking skills with respect to the demographic characteristics was carried out.

Systems-thinking Skills according to Gender

When the gender was used as the basis for comparison, data presented in Table 2 demonstrates that the mean scores of systems-thinking skills for male and female did not show much difference. The t-test result in the table indicated that there was no significant difference between the score of male and female respondents ($P > .05$). With a sample of this size, the test was powerful enough to detect a significance difference if it exists.

Systems-thinking Skills according to Gugusan

Following this, Gugusan was used to compare the mean scores of systems-thinking skills as presented in Table 3. The mean score obtained by Science and Technology was 25.9%, whereas, Business and Management and Social Sciences and Humanities achieved almost similar results namely 22.2% and 22.3% respectively. Both the mean scores were much lower than that achieved by Science and Technology.

Table 2: Systems-thinking Skills According to Gender

Gender	n	Mean	95% Confidence Interval of mean	Standard Deviation	t-Tests for Equality Means	
					t	Sig. (2-tailed)
Male	103	23.647	21.738 − 25.556	9.766	.202	.840
Female	130	23.411	22.019 − 24.804	8.024		

Table 3: Systems-thinking Skills According to Gugusan

Gugusan	n	Mean	95% Confidence Interval of Mean	Standard Deviation
Science and Technology	82	25.870	23.982 − 27.759	8.593
Social Sciences and Humanities	29	22.227	19.132 − 25.323	8.13
Business and Management	121	22.309	20.714 − 23.905	8.863

After considering the normality of the data set and homogeneity of variances ($P > .05$), ANOVA was carried out to determine whether there exist any significant differences among the different mean scores. The results are shown below in Table 4.

Table 4: ANOVA test for Systems-thinking Skills According to Gugusan

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	678.504	2	339.252	4.500	.012
Within Groups	17262.653	229	75.383		
Total	17941.157	231			

The ANOVA yielded statistically significant results ($F = 4.500$, $P < .05$). As there were unequal group sizes between the various Gugusan, Scheffé post-hoc test was conducted. The result showed in Table 5 indicates that there was significant difference(s) between the mean scores. The result reaffirmed that the mean score for Science and Technology was significantly different from the mean score of the Business and Management respondents.

Table 5: ANOVA Multiple Comparisons for Systems-thinking
Skills According to Gugusan

Gugusan (I)	Gugusan (J)	Mean Difference (I-J)	Std. Error	Sig.
Science and Technology	Social Sciences and Humanities	3.643	1.876	.154
	Business and Management	3.561	1.242	.018*
Social Sciences and Humanities	Science and Technology	-3.643	1.876	.154
	Business and Management	-0.082	1.796	.999
Business and Management	Science and Technology	-3.561	1.242	.018*
	Social Sciences and Humanities	0.082	1.795	.999

*significant at α = .05 level.

Systems-thinking Skills According to CGPA

Consequently, the CGPA was used to make group comparisons. It was found that the respondents from the higher CGPA group were able to get better scores compared to those in the lower CGPA groups as shown in Table 6. Respondents with CGPA 2.00 – 2.49 were only able to obtain a mean score of 21.2%, whereas respondents from CGPA 2.50-3.49 obtained a mean score of 23.3%.

Table 6: Descriptive on Systems-thinking Skills According to CGPA

CGPA	n	Mean	95% Confidence Interval of Mean	Standard Deviation
2.00 -2.49	45	21.240	18.623 – 23.864	8.723
2.50-3.49	156	23.290	21.979 – 24.724	8.653
3.50-4.00	32	27.812	24.739 – 30.885	8.524

After verifying the normality and homogeneity of variance for the data set, one way ANOVA was used. There was a significant difference between the respondents' systems-thinking skills according to their CGPA (F = 5.554, P < .05) as presented in Table 7. The Scheffé post- hoc test was then carried out.

The result as presented in Table 8 yielded a significant difference between those with CGPA 2.00-2.50 and those with CGPA 3.50- 4.00. Similarly, the difference was also significant for those with CGPA 2.50-3.49 and CGPA 3.50-4.00. However, the test showed no significant difference between the mean score of those with CGPA 2.00-2.49 and CGPA 2.50-3.39.

Table 7: ANOVA test for Systems-thinking Skills According to CGPA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	830.966	2	415.483	5.554	.004*
Within Groups	17206.550	230	74.811		
Total	18037.516	232			

*significant at α = .05 level.

Table 8: Multiple Comparisons for Systems-thinking Skills According to CGPA

CGPA(I)	CGPA(J)	Mean Difference (I-J)	Std. Error	Sig.
2.00 -2.49	2.50-3.49	-2.047	1.464	.378
	3.50-4.00	-6.567	2.000	.005*
2.50-3.49	2.00 -2.49	2.047	1.464	.378
	3.50-4.00	-4.522	1.679	.028*
3.50-4.00	2.00 -2.49	6.569	2.000	.005*
	2.50-3.49	4.522	1.679	.028*

*significant at α = .05 level.

In conclusion, the results above illustrated that among three demographic characteristic of respondents, only Gugusan and CGPA showed some influence on the systems-thinking performance, while gender was not a factor in determining the difference of systems-thinking scores.

Conclusions

The findings indicated that the general population performed poorly (23.5%) for systems thinking in these four performance tasks. In a similar study, Ossimitz (2002) reported that the average performance on each of his tasks was below 45%. His sample consisted of Masters and First Degree undergraduates. Contrary to popular belief, his sample performed slightly better than the Diploma students in this study.

One important aspect here is that this study was actually an attempt to quantify their informal systems-thinking skills as none of the respondents had received formal systems thinking education.

One thing for certain was that the instrument succeeded in capturing and quantifying these skills for comparative purposes. The instrument that was used here shared much similarity to that of Ossimitz.

The findings revealed that gender was not a factor that differentiated the performance of the students in systems thinking. A study by Ossimitz (2002) reflected that the performance of the males in his tasks was consistently higher than that of the females though he accentuated explicitly the inappropriateness to, thus, conclude that female subjects were generally inferior to their male counterparts. On the other hand, study by Sweeney and Sterman (2000) disclosed that there was some marginal effect with the males performing slightly better than the females on all their performance tasks though the effect was reiterated as only marginally significant. Therefore, further research into gender difference should be carried out to ascertain more conclusive findings.

The findings of this study showed that the performance of the Science and Technology respondents is significantly better than the Business and Management and Social Sciences and Humanities respondents. The possible reason for this difference could be that the Science and Technology students received exposure to the basic concepts of behavior over time graphs, feedback, ordinary differential equations, and identifying units of measure, basic understanding of probability, logic and algebra and other systems-related mathematical concepts which were also the underlying concepts of systems thinking. This finding was very similar to that of Sweeney and Sterman (2000) whereby their finding found that those with technical backgrounds did better than those in the Social Sciences and Humanities in one of their tasks.

Based on the findings of this study, CGPA did have some influence on the systems-thinking performance. The students with CGPA 3.50 – 4.00 outperformed those with CGPA 2.00-2.50 and also those with CGPA 2.50-3.49.

Though effort had been made throughout the period of surveying to ensure the best representative study, limitations were still found. It was clearly noticed that it was inadequate to accurately capture the qualitative nature of higher-ordered thinking process when a quantitative design was employed in this study. Other limitations arose from the aspect of small sample size for Social Sciences and Humanities, the length and depth of performance tasks constructed, the scoring rubrics designed and the lack of incentives provided to boost the attention span and time of respondents. Lastly, the low scores reported in this study may not due solely to the respondents' lack of knowledge. As commented by Sweeney and Sterman (2000), "Perhaps people understand stocks, flows, delays, and feedback well and can use them in everyday tasks, but do poorly here because of the unfamiliar and unrealistic presentation of the problems", the poor performance may be caused by the systems-thinking performance tasks given to the respondents were not put in 'familiar and realistic situations'.

There remain still many outstanding issues that have yet to be resolved of which many of them can be recommended for further survey: does mastering more systems thinking implies better performance in the non-routine problems? Is good training in mathematics or sciences sufficient to understand the basic concepts of systems thinking like stock and flow, time delays and feedback to

name a few? What other demographic variables influence the acquisition of systems thinking concepts? These are but a few of the issues that merit further research. The current work and the researchers' investigation are in the field of assessing systems-thinking skills.

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