Identifying variables dependency that influences a high level deliberation process in a CI-based Multi-agent System

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Abstract— Intelligence is the ability of using ones knowledge in solving a given problem in the most strategic manner. The efficiency of this logical ability is influenced by the knowledge depth that the individual had comprehended throughout his life experiences. The deeper knowledge the individual has about an event, the more confident the individual becomes at approaching at a successful outcome. In this paper, we describe the variables and their influence towards the knowledge depth of an agent in a multi agent system.

Keywords —agent, collective intelligence, personal intelligence, intelligence, deliberation, multi-agent system, cross-fertilization.

I. Introduction

The collaborative and competitive nature of multi-agent systems is visible through the simple social mode of communication that emerges between the human-agent interactions or agent to agent interactions. Simple mode of communication involves the fundamental actions carried out by the individual agents in achieving its desired goal.The sum of these achievements contributes to the overall group goal.Comparatively, the collective intelligence aspects of a MAS simply means that these agents should work together to produce more efficient solutions compared to the traditional approach. Importantly, CI is an emergent property of MAS rather than a gathering phenomenon of multiple intelligent agents.Therefore, in designing MAS with CI properties, formalization of a higher level deliberation process is essential.A high level deliberation process refers to the judgment comprehension of tasks, reasoning, and problem solving and planning[1].

Our proposed Collective Intelligence Algorithm, CIA is a meta-program that has the potential to control and coordinate a high-level deliberation process of a MAS. The algorithm is inspired by the emerging processes of controlled discussion, argumentation and negotiation between two or more intelligent human agents. These processes screens and validates the deliberation process through a cross-fertilization approach. The emergent property of the cross-fertilized ideas result as an intelligent solution that solves most optimization related tasks.

Here, the Collective Knowledge Transfer, (CKT) model facades through three inter-related phases. The phases include the pre-fertilization, cross-fertilization and post fertilization.

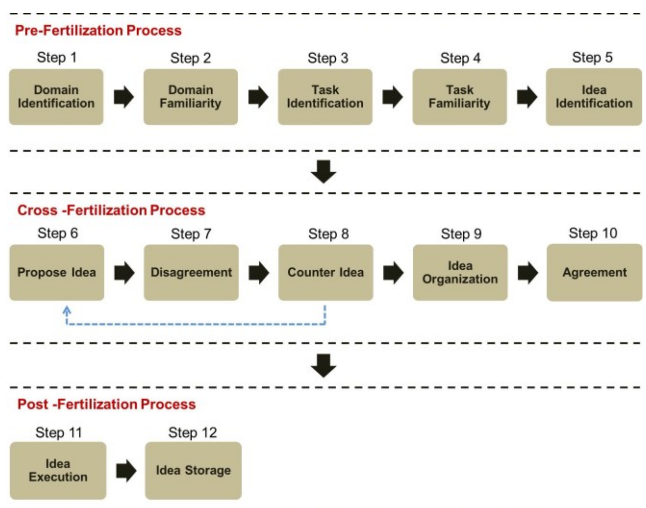

Fig. 1 The phases in the Knowledge Transfer Model

The attributes representing step one till step five is further explain in [2]. The table below provides the definition of the attributes.

TABLE I
Attributes And Definition

Attributes	Definition
Domain Identification	Determining and defining the scope of the problem.
Domain Familiarity	Understanding and identifying the similarity of the scope with the existing knowledge content.
Formation of a common Goal	Defining a universal aim that is to be achieved.
Task Identification	Defining the nature of the task by structuring the type of task that needs to be executed in order to achieve the common goal.
Task Familiarity	Identifying task similarity with existing knowledge content.
Idea Identification	Defining ideas that are associated to the execution of the task.

The attributes specified through the first five steps explains the comprehension process towards a task by an agent. We accustom that each agent is unique in a way through its variant knowledge depth when associating on a specific task. After all, the quality of decisions that an agent can make is clearly dependent on the quality of information available to it [3]. Understanding its knowledge depth and pursuing that knowledge in the action of discussion, argumentation, negotiation and the final decision making process describes its Personal Intelligence, PI. The table below describes the symbols used in this paper.

TABLE II
SYMBOLS AND DEFINITION

Symbol	Meaning
$\boldsymbol{W}$	World Knowledge
$\boldsymbol{K_n}$	Known Knowledge
$(\boldsymbol{W}-\boldsymbol{K_n})$	Unknown Knowledge
$\boldsymbol{Y}$	Experience
$\boldsymbol{E_n}$	Event
$\boldsymbol{x_n}$	Idea
$\boldsymbol{m}$	Knowledge Depth
$\boldsymbol{sf}$	Success Factor
$\boldsymbol{\Delta t}$	Efficiency Rate
$\boldsymbol{au}$	Authority
$\boldsymbol{cn}$	Confidence
$\boldsymbol{\alpha}$	Number of success upon the implementation of the solution
$\boldsymbol{\beta}$	Number of times a solution is executed
$\boldsymbol{t_{end}}$	End Time
$\boldsymbol{t_{start}}$	Start Time

Strategically, PI models the awareness and transferability aspects of an agents' knowledge with its other interacting agents. An agent initiates the process by reflecting on what it knows, $\boldsymbol{K_n}$ and doesn't know, $(\boldsymbol{W}-\boldsymbol{K_n})$ about its environment. While having the knowledge of an environment, the agent then seeks to understand the degree of familiarization it has acute through the various events, $\boldsymbol{E_n}$ of that environment by reconciling its previous experience, $\boldsymbol{Y}$**.** Two dependent variables, success factor, $\boldsymbol{sf}$and efficiency rate, $\boldsymbol{\Delta t}$ influences the degree of familiarization of the $\boldsymbol{K_n}$ of an $\boldsymbol{E_n}$. The degree of familiarization represents the knowledge depth, $\boldsymbol{m}$ of an agent.
In this paper, the focal discussion revolves in identifying the independent variables that influences the $\boldsymbol{sf}$and $\boldsymbol{\Delta t}$**.** This is an essential aspect of our CI model, as

- Firstly, they determine the knowledge depth, $\boldsymbol{m}$ of an agent.
- Secondly, they influence the preconditions: authority, $\boldsymbol{au}$ and confidence,$\boldsymbol{cn}$, that acts as the mobilizer to the cross-fertilization phase.
- Thirdly, they determine the level of intelligence that emerges during the social interaction.

We begin with these definitions:

Definition 1 :sf is influenced by, $\frac{\alpha}{\beta}$, in which α = number of success upon the implementation of the solution and β is the number of times a solution is executed.
Definition 2 :Δt is defined by $t_{end} - t_{start}$ in which t_{start} is the commencing time of a discussion and t_{end} is the time reflected when a decision is reached.

The idea is supported through a study with the intention of discovering the three hypotheses stated below:

Hypothesis 1: Knowledge depth is influence by the $\boldsymbol{sf}$ and $\boldsymbol{\Delta t}$.
Hypothesis 2: Knowledge depth is directly related to the $\boldsymbol{cn}$ and vice versa of an agent.
Hypothesis 3: The more knowledge an agent has the more confident the agent becomes at approaching a successful outcome.

II. RESEARCH OBJECTIVES

This research aims to identify the corresponding relationship between $\boldsymbol{sf}$ and $\boldsymbol{\Delta t}$ to the $\boldsymbol{m}$ of an agent. The investigation is carried out further to understand the correlation between the $\boldsymbol{m}$ and the $\boldsymbol{cn}$ of that agent. To achieve the aim of the research, the following objectives are proposed:

1. To evaluate the efficiency of each individual performance level based on a given task.
2. To compare the efficiency of each individual performance level on four given trials.

III. RELATED WORK

Biology inspired algorithms have gain detailed recognition in diverse fields, significantly due to their ability in solving many challenging optimization problems. Particularly, in the field of Multi Agent systems MAS, the execution of Swarm Intelligence, SI algorithms is pertinent in three different collective behaviors: spatially-organizing behaviors, navigation behaviors and collective decision-making. Brambilla [4]describes the three collective behaviors as :

- Spatially-organizing: behavior that focuses on how to organize and distribute robots and objects in space.
- Navigation behaviors: behaviors that focus on how to organizeand coordinate the movements of a swarm of robots.
- Collective Decision-Making: behaviors that focus on letting a group ofrobots agree on a common decision or allocate among different parallel tasks.

Specifically, the SI algorithms on collective decision-making behavior targets two needs. They are agreement and specialization. While the first places importance on swarm robotics consensus, the later encourages these swarm robots to leverage themselves over different possible task in order to optimize the system performance. Generally, achieving consensus amongst swarm robots is tedious as the best choice

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may vary every time, given the change present in the environment, situation and their facilities. The scenario is such, as these algorithms are a direct replica of the intelligent behavior exhibited in nature. This replicated intelligent behavior involves only fundamental cognition operations such as perception, attention, etc. [5].

On the contrary, higher level cognition processes refers to judgment comprehension of problems, deductive and inductive reasoning, problem solving and planning[6]. Sternberg [7] agrees to this by adding that higher order cognition is an information processing phenomena in which meta-cognitive factors of monitoring and control play the fundamental rule. To add, Dr. Levine [8] stated that "Higher order cognition is the pathway to complex thinking. It enables students to grapple with intellectually sophisticated challenges, integrate multiple ideas and facts, undertake difficult problems, and find effective and creative solutions to dilemmas whose answers are not immediately obvious."

As can be seen, humans exhibit higher level intelligence, while augmenting their intelligence may steadily improve the operations on decision making of MAS, it may also contribute significantly as a new optimization algorithm.

IV. Methodology

A study was conducted in the beginning of 2013 to understand the variables that influenced the knowledge depth of an individual who plays an active role in an intelligent social interaction. A probability sampling method is conducted to a total of 240 students from University Tenaga Nasional, (UNITEN). These students were undertaking the subject, "Statistics for computing". This was the subject of choice as the nature of the subject dictated more problem solving type questions. As a foundation subject, it comprises eight chapters. Prior to this study, these students had completed a total of six chapters in which they had undertaken five quizzes. At this point, the students were fit to undergo the study. This confirmation was given by their lecturer.

The study involved four mathematical tests (test1, test2, test3, test4) which were identical. Each test was identical in terms of the question type but differed as the variables in these questions were altered. The purpose of constructing the questions in this manner is to specifically test the students' familiarity towards the questions. The test questions were distributed across six chapters. Concurrently, the questions were prepared upon constant verification with the subject lecturer. Each test comprised of 15 objectives questions. The duration to complete each test was specified to 30 minutes.

The 240 students were stratified according to four sections which are section A, 1A, B and 2B. Each section respectively consists of 60 students. A random sampling method is then used to select every third student from the name list which were arranged alphabetically. Therefore, from each section there were 20 students whom were selected to sit for the examination. The 80 students were scheduled for the exam according to their class section. The tests were conducted for the duration of four weeks, in which the tests were scheduled respectively on Mondays, Tuesdays, Wednesdays and Thursdays.

In the first week, the students were given test1. The students were allowed to submit the completed test at any time within the 30 minutes duration. The commence time and the submission time is recorded for each student. The submitted papers were marked with constant verification from the lecturer. The total number of correct answers were tabulated and recorded. Similar procedure is applied in the next three weeks for the other three tests. Table III shows the distribution of questions based on the chapters.

TABLE III
CHAPTERS AND QUESTIONS

Chapters	Questions
Graphical Data Representation	3
Numerical Data Representation	3
Measures of Centers and Variability	3
Principles of Probability	2
Probability of Events Relations	2
Probability pf Random Variables	2
	15

The results were calculated based on each test. A table is constructed to capture the data for each section : A, 1A, B 2B. The elaborated fields for each section are as shown in the table below:

TABLE IV
SAMPLE TABLE AND FIELD FOR DATA COLLECTION

SECTION A

Student	TEST 1					
	Commence time	Completion Time	Efficiency Rate	No of Correct Answers	No of Questions	Success Rate

The purpose of this study is to identify the efficiency rate and success rate of each student from each section across each test. Therefore, a simplified version of the table which captures the data from the four tests is shown as below:

TABLE V
SAMPLE TABLE AND FIELD FOR DATA COLLECTION

SECTION A

Student	TEST 1		TEST 2		TEST 3		TEST 4	
	Efficiency Rate	Success Rate	Efficiency Rate	Success Rate	Efficiency Rate	Success Rate	Efficiency Rate	Success Rate

Once all the data are captured and filled in the table, the analysis is conducted by converting the data into two distinct line charts that represented each section. The first line chart shows the distribution of the success rate of each student across the four tests. The second line chart shows the distribution of the efficiency rate of each student across the four tests.

V. RESULTS AND FINDINGS

Figure two shows four graphs that displays the success factor, $\boldsymbol{sf}$ variable of 20 students from section A, 1A, B and 2B respectively. The success factor is calculated by dividing the total number of correct answers to the total number of questions given.

$$\boldsymbol{Success\ Factor} = \frac{\boldsymbol{total\ number\ of\ correct\ answer}}{\boldsymbol{total\ number\ of\ questions}}$$

The total number of questions represents the total frequency of attempts, $\boldsymbol{\beta}$ at a given time by an agent. The total number of correct answers represents the total success, $\boldsymbol{\alpha}$ out of the given attempts by that agent. As for each student, the $\boldsymbol{\alpha}$ value changes throughout the four tests and the $\boldsymbol{\beta}$ value remains fixed. As per each graph, the $\boldsymbol{sf}$ value ranges between zero to one. The graph indicates that the better the results are with the students the higher the value of the . Therefore, we categorized three separate range of values to represent the $\boldsymbol{sf}$.

Range 1 : $\mathbf{0.75} \le \boldsymbol{sf} \le \mathbf{1}$
Range 2 : $\mathbf{0.35} < \boldsymbol{sf} < \mathbf{0.75}$
Range 3 : $\mathbf{0} \le \boldsymbol{sf} \le \mathbf{0.35}$

During the progression from test one to test four, all four graphs show that the $\boldsymbol{sf}$ variable increases by an average of 20% in between each test for each student in each section. Evidently, this is due to the increase of value in the $\boldsymbol{\alpha}$ variable.

This phenomenon resulted from the gradual increase in terms of familiarization towards each questions in the four separate tests. As the students were examined on the same question types across the four tests, they were able to recall their previous experience and relate that in producing better solutions while progressing through the four separate tests.

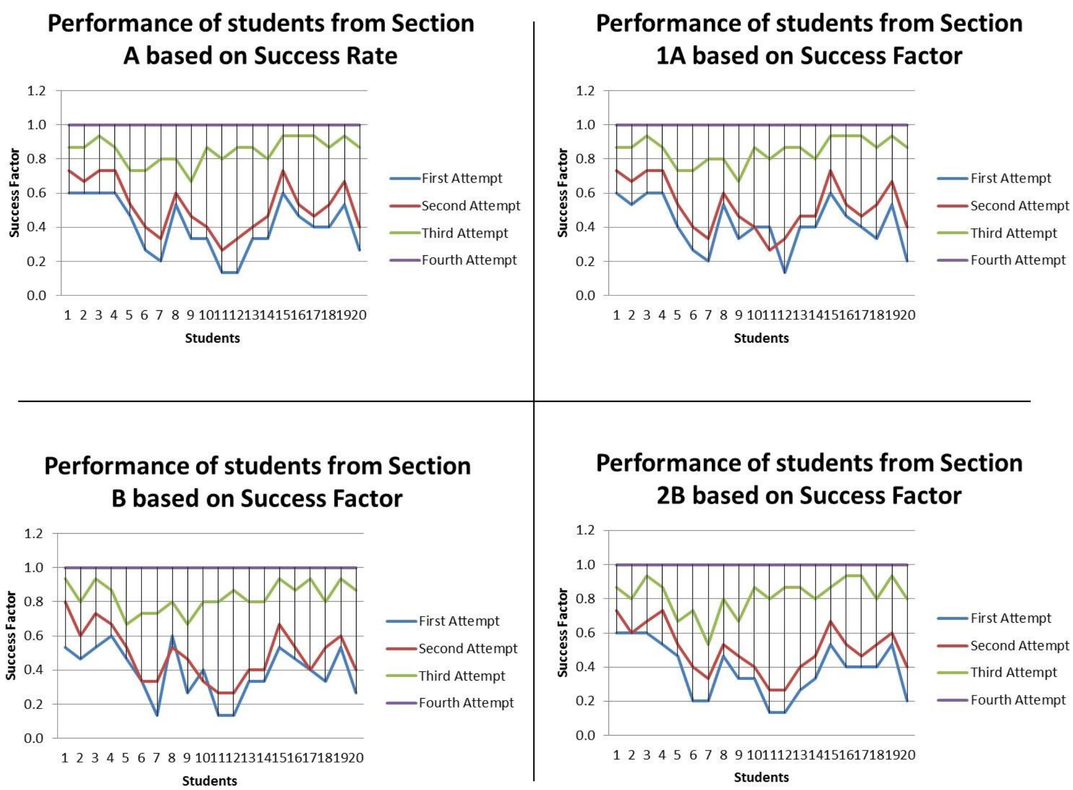

Fig 2. The graph of 20 students displaying the success factor for section A,1A,B and 2B

This finding suggest that the more familiar an individual is towards a problem the better he is at understanding the problem and assigning the best solution in order to solve that problem. His knowledge depth $\boldsymbol{m}$ increases as he experiences multiple practices on a similar problem. Here, we categorized the value of $\boldsymbol{sf}$ in relation to the depth, $\boldsymbol{m}$ level of the known knowledge as below:

When $\mathbf{0.75} \le \boldsymbol{sf} \le \mathbf{1}$ then $\boldsymbol{m} = \mathbf{1}$: high level depth of known knowledge
When $\mathbf{0.35} < \boldsymbol{sf} < \mathbf{0.75}$ then $\mathbf{0} < \boldsymbol{m} < \mathbf{1}$: average level depth of known knowledge
When $\mathbf{0} \le \boldsymbol{sf} \le \mathbf{0.35}$ then $\boldsymbol{m} = \mathbf{0}$: low level depth of known knowledge

Hereby, we say that students who show a higher sf value would have a high level depth of knowledge in solving future similar events more successfully. As an example, the analysis of data from section A students shows that Student 1's sf progression increased 40% from the first test to the forth test where else student 12's sf progression increased 70% from the first test to the forth test.

However, from the graph that represents the students from section B, student number eight and ten respectively performed better in their first test if compared to the second test. Both the students had a reduction of one in the $\boldsymbol{\alpha}$ variable between both tests. In order to understand this influx, we conducted an informal interview with both the students. The outcome indicates that both students were careless during the selection of the objective questions.

Figure three below displays the efficiency rate, $\boldsymbol{\Delta t}$ variable for 20 students from section A, 1A, B and 2B respectively. The $\boldsymbol{\Delta t}$ is the difference between the completion time of the test with the commencing time of the test.

$$\boldsymbol{Efficiency\ Rate = End\ Time - Start\ Time}$$
$$\boldsymbol{\Delta t} = t_{end} - t_{start}$$

Based on the graph, during the first test, all 20 students from each section took a complete duration of 30 minutes to complete the test. This is due to the reason in which the students were experiencing the test for the first time. However the $\boldsymbol{\Delta t}$ experienced a gradual reduction over the progression of the second, third and fourth test. The graph shows that all the students experienced an average of 50% reduction in terms of $\boldsymbol{\Delta t}$ when a comparison is made between the first test to the fourth test. As the students became familiar with the questions over the continuous second, third and fourth attempt, they are able to select and implement solutions at a faster rate, resulting in the overall reduction of the $\boldsymbol{\Delta t}$ variable**.**

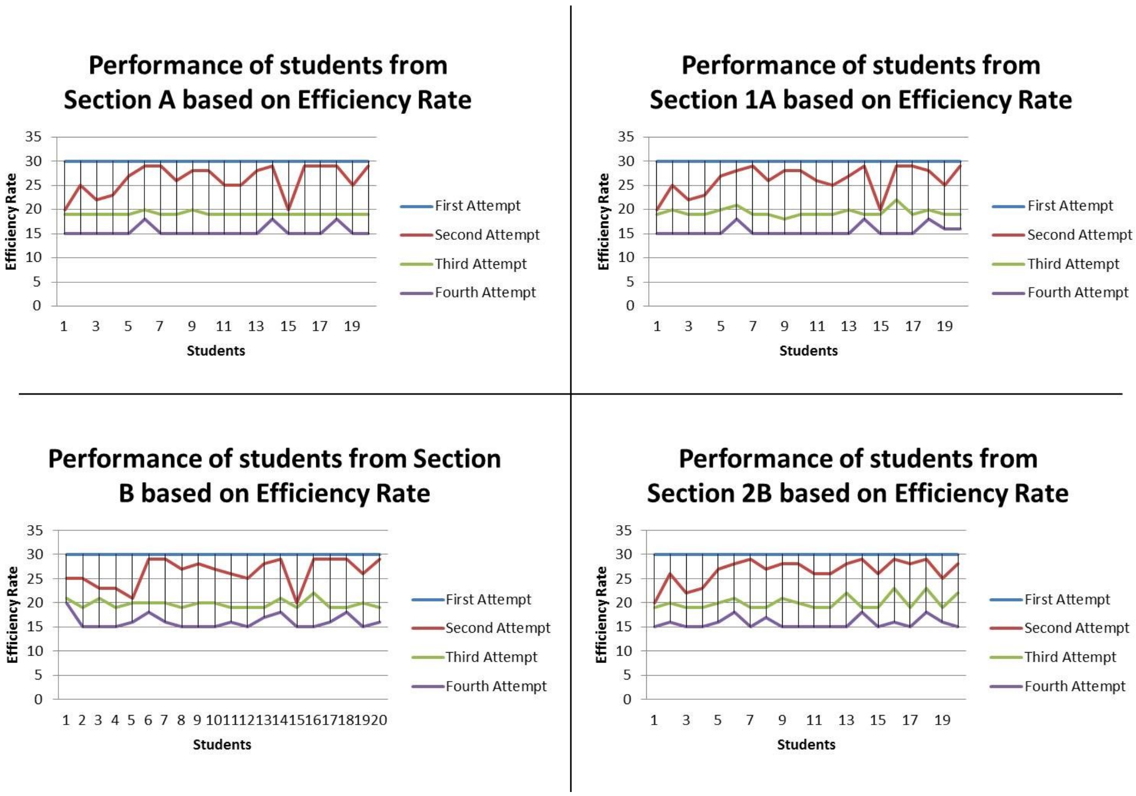

Fig 3. The graph of 20 students displaying the efficiency rate for section A,1A,B and 2B

The graph below shows the relationship between the $\boldsymbol{sf}$ variable and the $\boldsymbol{\Delta t}$ variable for the first student from section A, 1A, B and 2B. However, the results are similar for all 20 students from each section. The analysis from the graph indicate that the higher the $\boldsymbol{sf}$ the lower the $\boldsymbol{\Delta t}$. This indicates that the more $\boldsymbol{m}$ of the known knowledge of an individual the faster he is able to find a successful solution, which proves our third hypothesis. Ultimately, the $\boldsymbol{sf}$ and the $\boldsymbol{\Delta t}$ influences the $\boldsymbol{m}$ of an agent, in which this directly proves our first hypothesis. Subsequently, it is evident that as the students progressed through the tests, upon having an increase in $\boldsymbol{m}$ they become more confident at approaching the questions in the tests. The students were able to submit the completed question at a faster rate after each test without any form of hesitation shows that they are confident in their answers. Differing from their initial experience where they showed signs of hesitance. Hereby, we say that the $\boldsymbol{m}$ directly influence the confidence, $\boldsymbol{cn}$ level of an agent given an environment for it to experience upon and vice versa. This supports our second hypothesis. Therefore, we deduce that:

$$(\boldsymbol{m} \leftrightarrow \boldsymbol{cn}),\ \textbf{where}$$

$$\boldsymbol{m = 1}, \textbf{ if and only if } \boldsymbol{cn = 1}$$
$$(\ \boldsymbol{0\ < m <\ 1}\ )\ , \textbf{ if and only if } (\ \boldsymbol{0\ < cn <\ 1}\ )$$
$$\textbf{If } \boldsymbol{m = 0}, \textbf{ if and only if } \boldsymbol{cn = 0}$$

We describe the relationship of all the variables as :

$$Y(E_n) = \begin{cases} {}^{sf}_{\Delta t}K_n\,, & (0 < sf \le 1) \wedge (\Delta t > 0) \\ {}^{sf}_{\Delta t}\left(W - \sum_{n=1}^{x=0} K_{n+x}\right), & (sf = 0) \wedge (\Delta t = 0) \end{cases}$$

Where, in order for an agent to have a high level deliberation process, that agent should be able to comprehend a given problem by initially knowing its potential and using that potential to the fullest to attain at a successful outcome. In order to understand its potential, it should not only be equipped by a repository of $\boldsymbol{K_n}$ but also having an intense depth of that knowledge which is influenced by $\boldsymbol{sf}$ and $\boldsymbol{\Delta t}$ in our case.

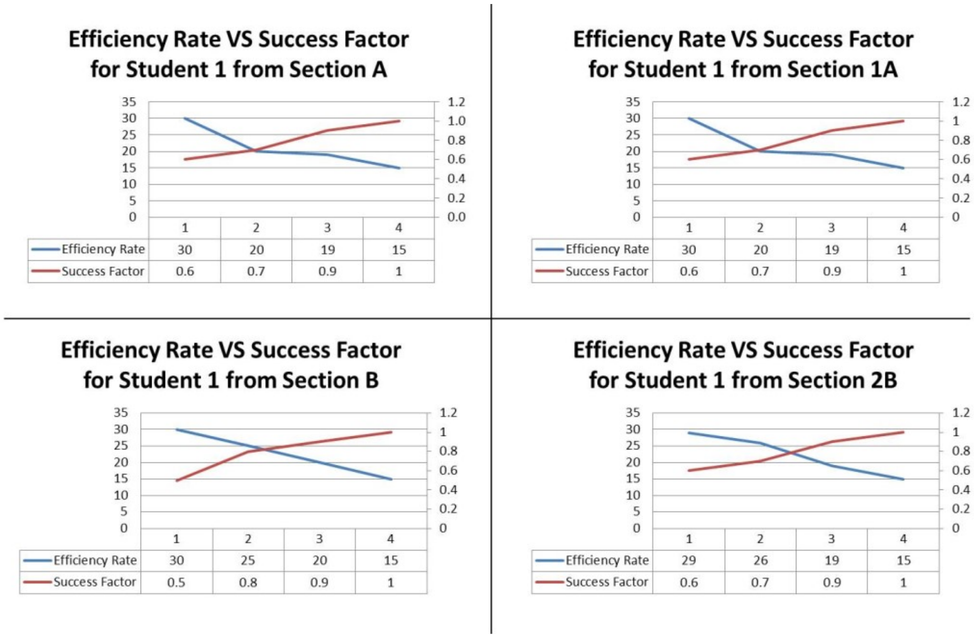

Fig 4. The graph of the first student displaying the efficiency rate and success factor for section A,1A,B and 2B

VI. Conclusion

Pre-fertilization is the process of espousing the ideas that can be generated from the collection of knowledge an individual possesses. It is important to note that any intelligent agent, who engages itself in any group related task, should retain a certain degree of knowledge depth. Knowledge depth is essential in the progression of a successful outcome. This very much influences the high level deliberation process of the MAS. In the pre-fertilization phase of the CKT model, the variables $\boldsymbol{sf}$ and $\boldsymbol{\Delta t}$ is essential in initiating the high level deliberation process. Both the variables determine the knowledge depth of the known knowledge of an agent. This will allow the agent to strategically select solutions which are highly successful upon application.

VII. Acknowledgement

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