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Exploring Fractal Characteristics in Education System

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ABSTRACT

This study aims to explore fractal characteristics of teachers and how do they influence student achievement. A fractal teacherhas aself-similarity characteristic essentially to control the optimal learning outcomes of their students. Results from experimental data have shown suchcharacteristics in two dimensions that constitute their unique abilities. These abilities are in a form of small fractal units and are nested copies from larger units. The smaller units are their individual characteristics unique to each other.Collectively, it comprises the behavioral approachesin teaching methods. Fractal teacher control differs and varies in implementation which is dependent on the fractal behavior of each group of students and yet achieves the same results, that is, improved positive learning outcomes. Statistical fractal analysis was used to measure student achievement. This method is far better than the usual classical statistics. A fractal dimension quantifies the fractal behavior of learning and provides information hidden in that learning system.

KEYWORDS: *Fractal characteristics, teacher control, student achievement, fractal analysis.*

INTRODUCTION

Fractals have become increasingly popular in educational setting. It was Mandelbrot (1983) who introduced fractals in the literature and has then exploded to several applications for advancement in mathematics, physical science, engineering, and chaos and complexity, to name a few. One of the most interesting applications is in education system (Erçetin Ş.Ş., Bisaso S.M., Saeed F., 2015). Activities in the higher education, such as organizing and planning entail fractal units that have self-similar characteristics. According to Raye (2014), fractals have broad applications in administrative organization because the system itself is found to have self-similarity property and fractal dimensions. For instance, a system on self-development of one student is similar to an employee, and up to the top management level. Having said that, this concept could be expanded to a smaller system such as classroom management system, that is, in the design and preparations for learning environments. This principle constitute fractal behaviour since the overall structure and approach of educational systems depicts chaos and complexity. In fact,Caena &Margiotta (2010) have asserted that the structure of education as a system, that is, teaching-learning activities, is characterized as self-similar dynamics at varying levels. It befits the understanding of complex living within the system. Conception of fractal characteristics should be the first attempt to find solutions on problems of the system. This paper attempts to explore fractals in the context of teacher characteristics with the hope that the framework and results would become useful in today's challenging fractal education system.

The ingredients of teacher characteristics should ensure fractal behavior. At this point, it is fitting to introduce the term *fractal teacher*. It has certain qualities involving multidimensional characteristics depicting quality teaching. Yan-zhong (2010) provides a framework of fractal organization. It is likewise harmonious to fractal teaching such that, it is complex, yet it has the ability to adapt to a dynamic learning environment. As a system, its self-similarity property constitutes a set of few yet specific teaching strategies appropriate for certain groups of students which is exactly a nested copy from a large teaching approach of an educational system. It is also important to consider the extent of the individual differences, and the properties of variations or similarities across students. This variation may include learner characteristics such as intelligence, personality, and attitude. These variables are essential components of self-affine or statistical self-similarity property of fractals in a complex and dynamic system. Outliers such as extremely low-level performing students which occur frequently and their continuous learning over time cannot be excluded. Moreover, it is also important to consider those learning activities in a classroom system characterized as interdependent, that is, reciprocating: students learn from each other while teachers do influence student learning, and hence fractal.

Self-similar behavior could be measured in terms of fractal dimensions or degrees of freedom. A fractal dimension measures the spread of the test scores, called its intrinsic dimension, or the number of domains or variables required to influence student achievement (Kumaraswamy, Megalooikonomou, Faloutsos, 2004). The higher the values of the fractal dimension, the greater is the information hidden in the data set (Oseledchik, Ivleva&Ivlev, 2017; Wang et al, 2017).

This present study also explores a shift from the classical statistics to fractal statistics. Oftentimes, data analysis involving student achievement are being treated with the Normal Probability distributions having the parameters mean and variance. In fact, fractals cannot be represented by a single number, e.g., average, as used primarily in classical statistics. This argument is based on the old notion that several natural phenomena such as test scores, follow the normal distribution, and is primarily based on the assumption of independence of events (McKelvey &Andriani, 2005; Andriani& McKelvey, 2009). However, Patac and Padua (2015) posited that using classical statistical test in an experimental data analysis, where a stable mean and finite variance were assumed to exist, would have led to confusing interpretations and conclusions. In fact, Selvam (2011) stresses the notion that statistical analyses using the Gaussian distribution underestimates the probabilities when data sets exhibit large variations. Real-life data such as student achievement are indeed highly varied. For example, consider a large class size of 50 heterogeneous students where most of them are at low-level performance, and together joining them are three extremely intelligent students. If we analyze the performance of the entire class in a daily assessment, their average performance will certainly misrepresent their mean performance. Such analysis has failed to account for the large variation and the effects for extreme values. In this case, the use of classical statistics does not necessarily provide convincing results.

As teaching itself is characterized as fractal, this study has sought to answer the questions: What comprises fractal teaching characteristics? What teaching abilities do fractal teachers have? How do fractal teachers influence student achievement?

THEORETICAL AND CONCEPTUAL FRAMEWORK

Fractal teaching characteristics are based on the principles primarily on teaching effectiveness, philosophy on behaviorism and fractals. This paper opines that fractal teachers are assumed to be effective teachers. Kivunja (2014)stresses that, for today's learners, effective teachers create quality learning environments to develop student higher-order critical thinking skills in problem-solving, become creative, innovative, and reflective. To make this realized, fractal teacher simpose teacher control in the learning process. They assist learners in harnessing self-regulation and autonomy (Drexler, 2010). The role of the teacher assumes as coach or a facilitator while increasing student autonomy in learning. This study has assumed that teacher control is embedded in the teaching system assumed to have fractal behavior.

Teacher Control

The philosophy of behaviorism best anchorage the concept of teacher control approach (Meisam, Z., Namaziandost, E., 2019). Behavior modification is a technique in learning environments that uses reinforcements and punishments in shaping student's behavior. Teachers could encourage creativity by creating a warm and permissive atmosphere in a diverse classroom, and eventually, capacitating each student to make responsible choices in their learning. However, despite all these efforts, teachers still face the tremendous challenge on individual differences in learning ability across students. The study ofStern (2017) suggests that the source of individual differences is rooted on genes and cognitive resources. Further, regardless of the level of intelligence, learning requires deliberate practice and time needed to acquire it.Pedagogical recommendations were consideredto address problems on teaching concerning individual differences across cognitive abilities (Pawlak, 2019). Recent studies focus on learning styles (Myftiu, 2015), scaffolding methods (Johnsen, 2017), and differentiated instruction (Joseph, Thomas, Ramsook, 2013).In this paper, teacher control comprises the teacher's ability to recognize individual differences (Hill & Shackelford, 2018), makes use of students' similarities and teaching approach suitable for the learning process (Elen& Bishop, 2014; Musso et al, 2019).

Conceptually, fractal teacher control has three (3) teaching domains as defined below. Each is having two levels either as low or high as shown in figure 1. It also shows four(4) quadrants representing the combination of teacher control. Student achievement variable is demarcated at 50th quantile between low and high control. The $2^3 = 8$ different combinations of these teaching domains are denoted *Dim*1referring to the teacher's ability to recognize individual differences, *Dim*2 referring to the teacher's ability to make use of similarities, and *Dim*3 referring to the teacher's ability to make use of varied teaching approach.

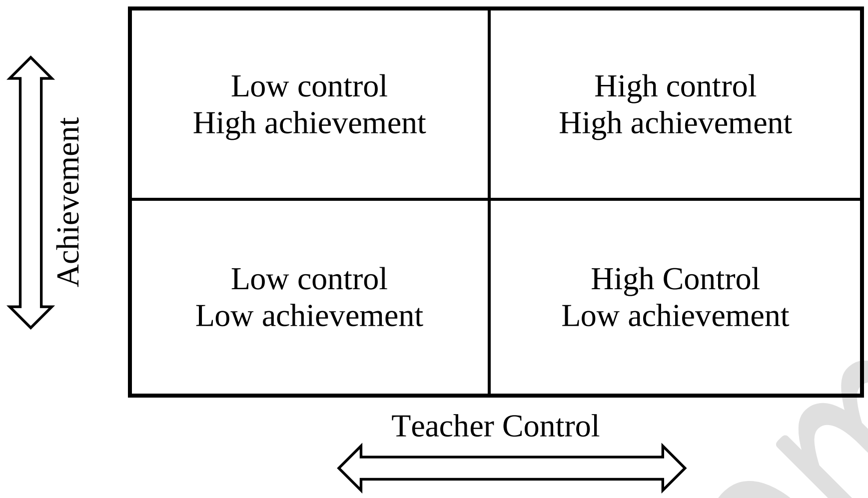

Figure 1. Teacher Control vs Student Achievement

Table 1.
Possible combinations for Teacher Control

Possible events	Dim 1	Dim 2	Dim 3	Teacher control is…
1	+	+	+	High
2	+	–	+	High
3	–	+	+	High
4	+	+	–	Low
5	+	–	–	Low
6	–	+	–	Low
7	–	–	+	Low
8	–	–	–	Low

In table 1, the positive sign (+) indicates the presence of the teacher control, else, the absence (–). Any given teacher could only take one out of eight possible events, or $12.5\% (= 1/8)$ on the equally likely assumption. A teacher is said to have high teacher control if at least two of the three teaching domains are present, provided that *Dim*3 is always present. This definition of teacher control induces three possible combinations for high teacher control and five combinations for low teacher control. These combinations also imply that roughly $37.5\% (= 3/8)$ of teachers would possess fractal teaching abilities,while $62.5\% (= 5/8)$ would not. Scoring procedure is presented in table 2.

Table 2.
Scoring for Teacher Control

Rating Scale	*Description*
0.80 – 1.00	Very high
0.60 – 0.79	High
0.40 – 0.59	Average
0.20 – 0.39	Low
0.00 – 0.19	Very low

Fractals

Mandelbrot (1983) used the term *fractals* to describe natural occurrences, processes and objects as having anomalous dimension. M. Pons and J. Dodds (2015) likewise describe fractals objects have properties called self-similarity (Sahoo, Barman & Davim, 2011; Pegoretti & Ricco, 2003) and have iterative patterns. Natural systems such as cloud formation, the structure of the trees and the forest, earthquake patterns, weather systems, human heartbeat, and cancers exhibit fractal properties (Lennon et al, 2015). While objects have spatial fractal characteristics, phenomena could exhibit fractal behavior without necessarily having spatial form (Pilgrim and Taylor, 2018). A more interesting phenomenon is that the human cognitive ability exhibit fractal characteristics (Nuhfer& Hoffer, 2010).Theoretical fractal is a self-similar set of points and are being quantified through a non-integer (or fractional) numerical values, commonly known as the fractal dimension (Larsson, 2018). Fractal dimension describes the changes in the variability of scores, hence a good indicator for the "spread" of the data set. It estimates of the degrees of freedom and provides useful information that are "hidden" in the data set (Kumaraswamy,Megalooikonomou, Faloutsos, 2004). That is, the experimental data set used in this study (e.g. student achievement) is said to be statistically self-similar if the said data obeys the power law on a given range of scales. Patac and Padua (2015) have shown that the fractal dimension λ of a set of data is:

$$\lambda = 1 + (\bar{y})^{-1}, \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} \log\left(\frac{X_i}{\theta}\right)$$

where $X_i$represents the set of student achievement scores for n students,θas the smallest value of X_i, and $\bar{y}$ as the mean of transformed data set. The λmeasures the fractal characteristics of the actual performance of students in a paper-pencil test.

METHODOLOGY

Participants

An experimental group of fifteen (15) full-time tertiary mathematics teachers participated in this study. Teaching positions on full-time status were granted to them since they exceeded the minimum standards for such job qualifications. These participants-teachershave completed either pure mathematics or applied mathematics undergraduate courses and have finished corresponding graduate courses.

Instrumentation

There were two sets of instruments used in this research. The first set was the researcher-made student achievement test for mathematics classes. The test items underwent conscientious revision by selected content experts and were carefully adjusted to cover the necessary learning goals and duration to finish the assessment. The tests were item-analyzed using a software and the final test draft obtained a Cronbach's alpha of 0.827.

The second set was a researcher-made questionnaire and checklist. It was aimed to measure the variables for fractal teaching characteristics. For *Dim*1, the main indicators include providence of information necessary for learning, feedback tools, recognition of individual differences, encouragement, acceptance, support for learning and performance. For *Dim*2 and *Dim*3, indicators include collaborative learning strategies, teaching cues, problem solving techniques, scaffolding and differentiation strategies for learning styles, and alternative assessment methods. These instruments underwent validity and reliability tests. Cronbach's alpha results indicate 0.812 for *Dim*1, 0.757 for *Dim*2, and 0.763 for *Dim*3. Students under each of the 15 teachers were made to respond in the questionnaires for items in*Dim*1 and in*Dim*2 after the duration of the experiment. Selected external mathematics faculty together with the researcher made classroom observations for the 15 teachers and then indicate their responses for the items in *Dim*3. In addition, comments and remarks were made in that same instrument as vital source of information to strengthen the claims of this study.

Fractal Statistical Analysis

Fractal analysis began with careful examination of the pretest and posttest results obtained from the students on each of the teachers. The expression (1) was used to transform the test results.

$$(1) y = f(x) = \theta e^{X_i} \quad , X_i = x_1, x_2, \dots, x_n, \theta = min\{X_i\}, \qquad i = 1,2,\dots,n \text{ for } n \text{ students}$$

Data transformation was necessary in adherence to the fundamental theorem of fractal statistics. It states that scores exhibit fractal characteristics if and only if the $\log\left(\frac{X_i}{\theta}\right)$ is exponentially distributed (Patac&Padua, 2015).

The next step was to compute for the fractal dimensions, denoted byλ, of the test scores by use of the mathematical expression (2).

$$(2) \lambda = 1 + (\bar{y})^{-1}, \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} \log\left(\frac{X_i}{\theta}\right)$$

Graphictools area much 'quicker' way to detect fractals.A resemblance of the histogram in figure 2depicts fractal behavior. This graph suggests that abundance of frequency for low scores as compared to the larger scores.

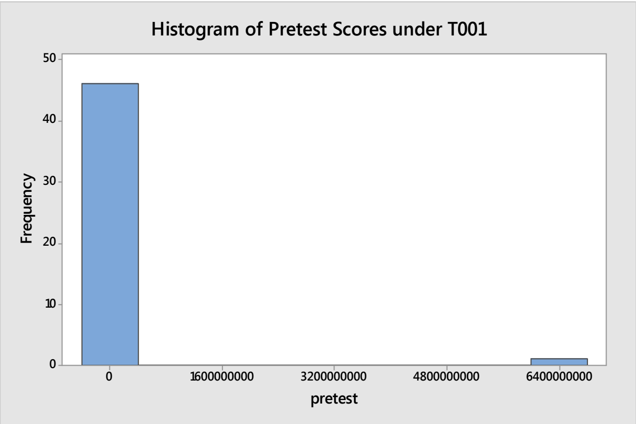

Figure 2. A Fractal Score

Fractal Teaching Characteristics: Two Criteria

Fractal systems, being self-similar, are also self-organizing (Erçetin Ş.Ş., Bisaso S.M., Saeed F., 2015). In the school system setting, fractal behavior allows educational system to adopt and restructure(Yan-zhong, 2010). In a similar fashion, teacher control is an instructional strategy based primarily on behaviorism. Hence, a fractal teacher controlis characterized as self-similar and self-organizing. For example, themost sought-after differentiated instruction is specifically addressed to diverse learners. This could serve as a small fractal unit, which is exactly a copy from a larger fractal unit as constructivist and behavioral teaching approaches. To assess if the implementation of such instructional strategies were indeed successful, this study has explored the learning gains from the students. Hence, it sets up two main criteria: first, learning gains score would have served as success indicator; secondly, observable changes in fractal dimension brought by fractal teaching.

Learning gains score. Essentially, a pretest is a measure of the students' initial learning ability, while the posttest is a measure of the amount of learning they have received from teaching. The learning gains score is the difference between these two scores. Positive gains score is indicative that learning has taken place; else, not. Positive values are our interest.

Reduced fractal dimension values. Fractal teachers are regarded asquality and effective teachers so that the learning activities produce positive learning outcomes. All learning activities inside the classroom that were carried out were practically based on the outcomes of the students' initial abilities. For example, the learning environment is self-structured(i.e.fractal) in a student-centered learning paradigm. Fractal teachers carefully control the amount of information upon the students for them to construct meaning from where learning interaction took place. This means, the prior state of its learning environment is expected to behave fractal. Then the "teaching intervention strategies"(i.e. fractal teacher control) has made changes in the behavior of the students for them to "fit in" their own learning. Hence, the second criterion measures the amount of teacher control during the intervention process. It is also expected to induce positive learning outcomes. Intuitively, a reduced fractal dimension could either mean a fractal or a non-fractal.

RESULTS

Table 3.
Overall Results

Teacher	*Gains Score*	*Fractal Dimensions, λ*		*Teacher Control*			
		Pretest	*Posttest*	*Dim 1*	*Dim 2*	*Dim 3*	*Mean*
003	7.080	2.542	2.371	0.7912	0.5267	0.9287	0.7489
006	0.343	2.698	1.776	0.9470	0.6202	0.9524	0.8399
007	12.906	2.634	1.987	0.8024	0.6061	0.9500	0.7862
012	3.657	2.081	1.837	0.7918	0.6750	0.7857	0.7508
013	6.480	2.421	1.713	0.6642	0.6541	0.7431	0.6871
001	1.086	2.329	2.534	0.7973	0.4318	0.7833	0.6790
002	3.285	1.871	2.315	0.7160	0.3000	0.6778	0.5646
004	0.542	1.860	1.797	0.8214	0.5740	0.6556	0.6837
005	2.147	1.817	3.335	0.4267	0.6600	0.5222	0.5363

008	–2.125	2.930	2.235	0.7562	0.5850	0.7389	0.6934
009	–0.500	2.372	2.478	0.9241	0.6122	0.7611	0.7658
010	1.750	2.578	2.623	0.8390	0.7063	0.8444	0.7966
011	3.000	2.196	2.136	0.8300	0.5313	0.9285	0.7633
014	0.491	2.016	2.339	0.7917	0.7988	0.6190	0.7365
015	1.536	1.953	4.630	0.7830	0.6450	0.8571	0.7617

Table 3 shows the overall results for teacher control, learning gains score, and the fractal dimensions of pretest and posttest. Teacher control will be presented later. On the basis of the first criterion, all but two (2) teachers have produced positive average gains score, to wit, teachers 008 and 009.On the basis of the second criterion, eight (8) teachers were able to reduce fractal dimension of test scores from the pretest to posttest. The posttest results for those who agreed with the first and second criteria have been further analyzed. Do posttest results behave fractal or not? The test for normality was used to assess non-fractal behavior in table 4.In fact, Corvi et al (2017) have conducted a fractal analysis on data that followed a normal distribution (p. 28).

Table 4.
Results from Posttest Normality Test

Teacher	*KS_1statistic*	p-*value*	Normal?
002	0.070	> 0.150	Yes
003	0.113	=0.108	Yes
006	0.110	> 0.150	Yes
007	0.133	> 0.150	Yes
008	0.106	> 0.150	Yes
009	0.129	> 0.150	Yes
012	0.138	= 0.090	Yes
013	0.102	> 0.150	Yes
015	0.139	> 0.150	Yes
001	0.142	= 0.026	No
004	0.234	< 0.010	No
005	0.225	< 0.010	No
010	0.154	= 0.038	No
011	0.168	< 0.013	No
014	0.162	< 0.010	No

Table 4 presents the results for the Kolmogorov-Smirnov normality test conducted at 5% level of significance for the posttest results (Hassani& Silva, 2015). The results were the bases of identifying posttest scores that indeed have resulted to normality. The results have shown that nine(9) teachers have produced normally distributed posttest scores (*M*=2.371, *SD*=0.9529). A simulation was carried out to test the significance of the mean λ for which $n = 10{,}000$, and has produced a 95% confidence interval of $2.349 \le \lambda \le 2.386$. This interval implies that the average fractal dimension λ as a result of teacher control ranges from 2.349 up to 2.386. Hence, the posttests scores indicate the extent of teacher control at which it produces either at fractal or at "normal" state. The results have served as the characterization between a fractal teacher and a non-fractal teacher as summarized in table 3.

Teacher Control and Student Achievement

In table 3, five (5) teachers were classified as fractal teachers and ten (10) asnon-fractal teachers. The results have indicated that fractal teachers have at least a high rating, that is, on average, "*very high*" (M=0.7993) in *Dim*1, "high" (M=0.6164) in*Dim*2, and "*very high*" (M=0.8720) in *Dim*3.Indeed, fractal teachers have high teacher control in students' learning outcomes by making use of varied teaching approach to address individual differences, as defined indicators based on the instruments used. The results have also shown the following ranks of the five teachers in terms of teacher control was in the order: teacher 006 (M=83.99), teacher 007 (M=78.62), teacher 012 (M=75.08), teacher 003 (M= 74.89), and teacher 013 (M=68.71). All ratings are above the threshold of 60%(table 2) indicating that a high teacher control approach was imminent in all the five considered fractal teachers.

Further, it is important to note that the results in table 3 show in agreement with the results in the two underlying criteria, that is, fractal teachers were able to produce positive gains scores and have reduced the fractal dimension of the posttest to "normalize" student outcomes. This is so far the overall effects of fractal teaching. These effects of teacher control towards student achievement are visualized in figure 3.

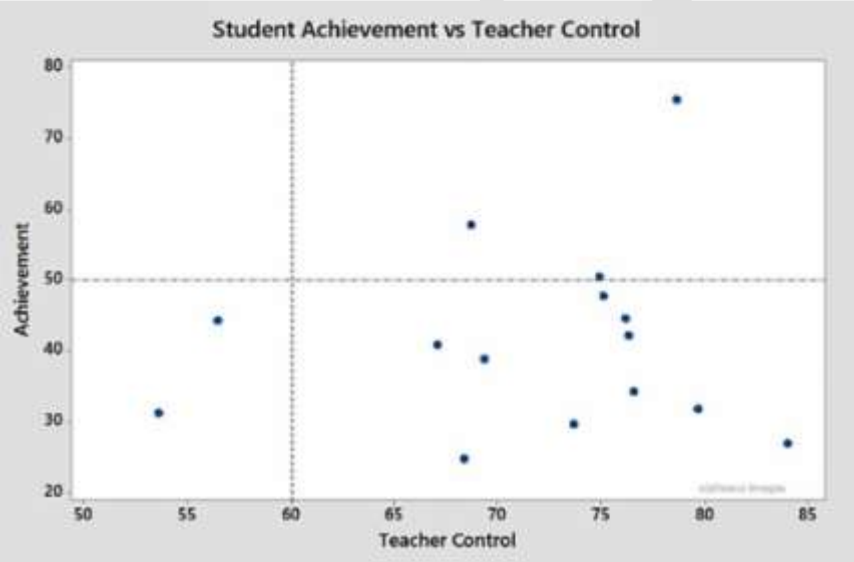

Figure 3.
Student Achievement vs Teacher Control

In figure 3, three (3) fractal teachers whose student achievement raw scores were above the 50thquantile. These were teacher 007 (M=75.42), teacher 013 (M=57.87), and teacher 003 (M=50.53).However, the results for teacher 012 (M=47.81) and teacher 006 (M=26.95) were below the 50% mark.

DISCUSSIONS

Fractal teachers have "unique" teaching abilities. These teachers impose high control on a group of students having fractal behavior. Their teacher control is a locus of ability in using varied teaching approaches to optimize learning (e.g. *Dim*3). However, the extent to which the control was imposed is not uniform from one group of students to another. Let us compare the results for two fractal teachers 006 and 007 based in table 3. The fractal dimensions of their pretest and posttest results are almost identical. However, the disparity of their learning gains result is too large. This means that the amount of teacher control implemented is dependent on the fractal behavior of a certain group of students. Further, fractal behavior is unique to every group. It is clear that two fractal teachers implement learning activities differently and yet has achieved the same improvement of student outcomes. Indeed, these results have two important implications.

First, fractal teachers are highly likely self-similar, that is, they exhibit the same teaching qualities across a wide range of teaching abilities. Given a set of their skills, fractal teachers indeed influence student achievement. They are able to detect individual difference across a group of students (i.e., *Dim*1).For example, if the fractal dimension of students' initial abilities is 2.698, then it is expected that there are at most three (3)"hidden" dimensions for such abilities (e.g. Kumaraswamy, Megalooikonomou, Faloutsos, 2004).In fact, Mandelbrot (1983) posits that fractal dimension property represents the space-filling property. This characteristic is synonymous to the amount of "hidden" information contained in an object. Fractal teachers are conceived to detect such hidden dimensions, that is, hidden learning dimensions that need necessary and appropriate learning "interventions" to achieve optimal learning possible (Decena et al, 2017).These hidden learning dimensions are distinct for each group since such information came from a wide range of different individuals. Further, fractal teachers are able to "fill-in" the learning needs of their students at varying levels.

Second, student achievement should not be measured on the basis of a set of "standard" criteria. A typical example are the norm-referenced assessment methods (Lok, McNaught & Young, 2016). Today's education system relies heavily on norm-referenced grading system that are based on averaging. Let us again, compare the results for teachers 006 and 007 in table 3. The difference of their learning gains score result is about 12.563 which is almost the gains score of teacher 007.In figure 3, teacher 007 has achieved the highest student achievement results, however, its fractal dimension is remarkably close to the fractal dimension for teacher 006 who obtained the raw score far below the 50% quantile. If a norm-referenced system was indeed used for the students of both teachers 006 and 007, then the students under teacher 006 would certainly all get failed. Practically, if the basis of specific assessment is on averaging, then many students may fail in a given examination. Unfortunately, this kind of scenario does not provide a morerealistic picture of student achievement. In the case of teachers 006 and 007, student achievements were not measured in terms of the usual averaging of posttests scores. The use of fractal dimension quantifies how much teacher control was implemented. Fractal teachers are able to detect the hidden information that are needed for learning because they know what suits for a group of learners. However, this paper limits on that note and motivates readers for further research about the hidden information found on the data. Fractal dimensions, instead of the usual averaging, provides a better benchmark on the "actual" learning received by the students from their fractal teachers. In fact, Padua et al (2013) have shown that fractal dimensions are more reflective of the true and natural behavior of phenomena.

CONCLUSION

In the light of these results, fractals do exist in education system. Self-similarity property is inherent to this system. The main ingredient of fractal characteristics is teacher control which defines the teacher's ability to recognize individual differences and the ability to vary instructional strategies to optimize students' learning outcomes. Teacher control is a behavior that dictates the design and structure of teaching-learning environment fitted for a given learning system. These unique abilities are small fractal units and are nested copies of larger units of teaching methods for behavioral and constructivist approaches. The characteristics defined in this study could provide vital information in the efforts for further educational reforms at fractal state. Fractal dimension essentially quantifies the hidden information embedded in the learning system and hence a better measure for student achievement.

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