Conceptualization of chemical kinetics using a visually enhanced teaching technique; a developed MS Excel worksheet/system

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Abstract: Chemical kinetics or reaction kinetics is renowned as a division of physical chemistry which includes with understanding the rates of chemical reactions. As physical chemistry lessons play a vital role in secondary level chemistry syllabus in Sri Lanka, in order to understand the concepts of chemical kinetics the use of only traditional chalk and board method is inadequate. Accordingly, this study was carried out with the objectives of developing a suitable teaching aid using MS Excel and visual basic to conceptualize the theories in chemical kinetics enabling to promote the insight while upgrading the standard of chemistry education by combining it with visually enhanced teaching. Thirty students with similar knowledge level were randomly divided into two groups and same chemistry lessons were conducted leaving only one difference in their instructional method; the MS Excel worksheet was used along with the traditional chalk and board for one group while only the traditional chalk and board method was used for the other group. Same question paper was given for both groups at the end. The student's t test was used as the analytical tool to analyze the results. The statistical results confirmed that the used system supported the students to visualize and understand the concepts related to chemical kinetics in a better manner. For this sample, at 95% confidence level t calculated (10.372) is greater than t tabulated (2.048) suggesting that this proposed teaching aid improved the students' knowledge and understanding significantly than that of the ordinary chalk and board method. This developed MS Excel worksheet/system together with its findings will be beneficial to several sectors such as chemistry students, teachers, school administrators and policy makers..

Keywords: chemical kinetics, chemistry, MS Excel worksheet, chalk and board method

1. Background, Motivation and Objective

A. Background

The approaches of using audiovisual aids to stimulate learning that persists and enabling students to enjoy learning through indirect experience by using audiovisual materials were two research and development areas which were prominently addressed by an exceptional educationist, Edgar Dale [1]. Although he published the concept of "Cone of experience" in 1960s his effort remains to inspire educational technologists in the 21st century as well [2]. It is a model that combines several theories related to instructional design and learning processes.

Nowadays, this "learning by doing" has become accredited as "experiential learning".

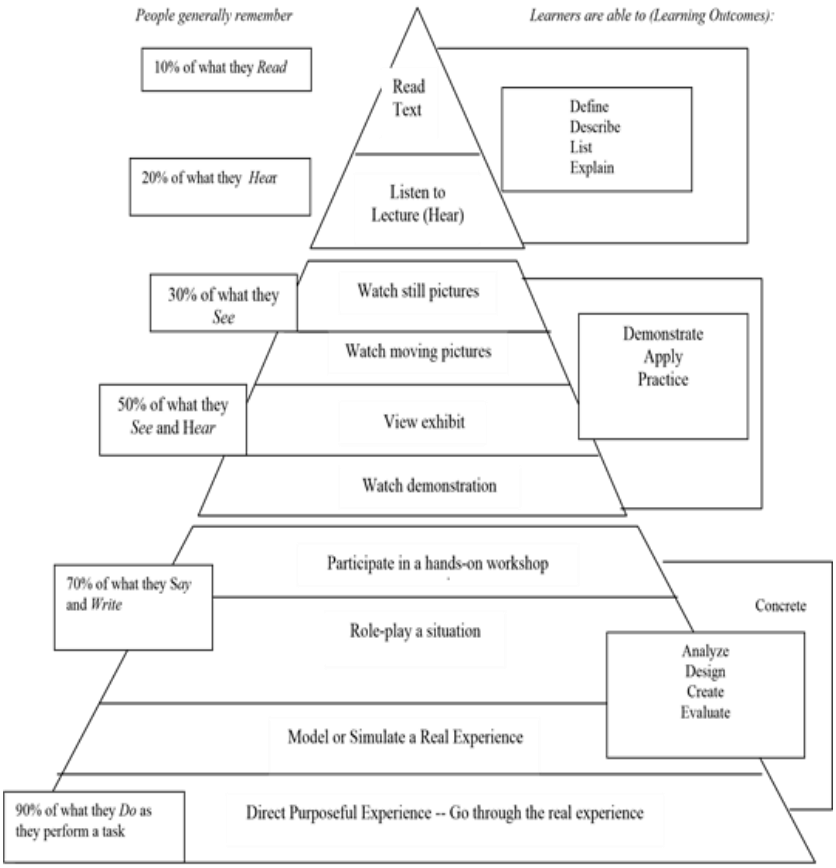

Fig. 1 Dale's Cone of Experience [2]

In moving towards the peak of the Cone from direct experiences to verbal symbols, the degree of abstraction gradually increases. As a result, learners become an audience rather than participants. The bottom of the Cone represented "focused experience" that is encountered by the senses of the body and which is highly effective for the learner. But in contrast verbal symbols (i.e., words) at the top of the cone are highly abstract. Visual receiving like exhibits, demonstrations are placed in the middle with an approximate retention or recall capacity of 50%. It also suggests that when choosing an instructional method, it is important to integrate the participation of the students to the process which is vital for the successful implementation of a learning activity. Therefore, many educational applications have been created so that the students can learn theoretical concepts through visual and interactive manner.

Utility of the concepts in Dale's Cone in teaching and learning of a science subject like chemistry is phenomenal as it involves the understanding of many abstract concepts. Chemistry which is often said to be the "central science" as it serves as the interface for most other sciences. Chemistry education is an interdisciplinary field which is consisted with all aspects of teaching and learning chemistry. Therefore "purposeful learning" of chemistry is a challenging task. Instructional method plays a crucial role and has a direct link between the problematic concepts and the student's ability to solve them. As a practice most of the chemistry teachers follow a traditional method to deliver the subject content using chalk and board method in a teacher centered learning environment which is not sufficient to arouse the curiosity of the student. In fact, this passive learning approach deserts some of the capable students stranded. Stimulation of the students thinking process through active participation and visualization fascinates young minds enabling them to resonate with their teachers.

Many teaching aids are available these days that can be used for effective instructional process in chemistry. They can be classified as visual aids such as actual objects, models, pictures, charts, maps, flash cards, white board, slides; audio aids like radio, tape recorder and audio-visual aids which includes television, film projector, film strips, multimedia *etc.* Teaching aids are useful in teaching learning process, but they contain some limitations such as: learners may form inaccurate imprints, not giving the full image of a subject, difficulty in identifying key points *etc*. Despite of these insufficiencies teaching and learning of chemistry can be transformed to a highly effective nature when it is combined with appropriate teaching aids.

Abundant means and benefits of using computers and other technological aspects can be recognized for the teaching learning process as a tool, medium and a tutor. Some of them include; instructing the students using

power point slides, word documents or web pages and using hyperlinks for better concept clarity; video conferencing, chat and email for better communication, viewing the current syllabus through website of the concerned school board *etc*. The use of MS Excel spreadsheets has been broadly encountered in the educational journals and conferences as one such method. These studies have pointed that due to its wide-ranging capability in processing and presenting data MS Excel program is very useful in chemistry teaching [3]. MS Excel could be used as a teaching tool because of its ability to solve a variety of chemistry problems including calculation and plotting of graphs. Furthermore, both the teachers and students are accustomed to MS Excel software enabling themselves to expand the academic horizons with enthusiasm and understanding. Spheres of chemistry that practice MS Excel include kinetics, titration curves, isothermal gas law and calculations of atom/molecule orbital *etc*.

B. Motivation

In Sri Lankan context chemistry is introduced as one of the main science subjects in secondary level of national curriculum. General Certificate of Examination Advanced Level (G.C.E. A/L) Chemistry syllabus recommended by the National Institute of Education (NIE) has been designed targeting to provide basic knowledge required in the subject for higher education in Sri Lanka. Despite of its significance, the performance of the learners in national exams remains low. Some areas of the syllabus like physical chemistry can be recognized as the most challenging for the students to capture deeming least attention. This is evident by the evaluation report for G.C.E. (A/L) chemistry published by the department of examination, Sri Lanka [4]. According to the available research findings poor performance can be attributed to factors such as poor instructional methods, attitudes of the students and teachers towards the subject and lack of resources. Integration of computer technology for the instructional purposes and thereby reinforcing the teaching and learning process of chemistry towards more student-centered approaches could improve students' performance in chemistry. A limited number of investigations were concentrated on this subject matter in Sri Lanka. Therefore, considering the existing gap of research in Sri Lanka an MS Excel worksheet/system was developed and used for the purpose of teaching concepts in chemical kinetics.

C. Objectives

One of the objectives of the study was to develop a teaching aid using the inbuilt functions of MS Excel to explain theories in chemical kinetics.

This in turn upgrades the standard of chemistry education by combining it with visually enhanced teaching.

Introduction the created template to chemistry students and teachers and evaluate their acceptance was another objective of the research.

Final objective of the research was statistically analyzing the effectiveness of the system.

2. Statement of Contribution/Methods

A. Statement of contribution

MS Excel worksheet environment becomes a dynamic and responsive work environment when formulae and functions are used. Most of the research done were allotted with the students' attitude towards the use of new technology. Zain, Rahman and Chin (2013) in their research developed MS Excel worksheets to teach few chemistry lessons selected from physical and inorganic chemistry in the high school and first / second year university syllabi [5]. The survey method was used to obtain the views of the students and teachers regarding the application of MS Excel in their study process.

Akcayi, Durmaz, Tuysuz & Feyzioglu (2003) conducted a study to compare the effects of computer-based learning and ordinary method on students' performance and attitudes in analytical chemistry [6]. From the department of chemistry education at Dkuz Eylul University, Turkey a group of 195 learners were selected randomly and divided into three groups; a control and two experimental. For the purpose of teaching analytical chemistry topics, two different computer-based methods; new learning software called HEHAsit and a MS Excel program were prepared by the researchers and applied to the two experimental groups at the same time the control group was taught by the traditional method. An attitude questionnaire and an achievement test related to analytical chemistry were developed and applied to all three groups comparing the outcomes.

Sinex (2007) developed a series of interactive Excel sheets or Exceletes for discovery learning in general chemistry [7]. According to the researcher, when the students were allowed to involve in various Exceletes and associated activities they receive the opportunity of engaging in higher-order thinking and science processing skills. This was done in MS Excel using different formulae. As mentioned Exceletes improve the interactivity to instruction in online classes. Some mathematically advanced topics such as competing and consecutive reactions in organic chemistry can be explored from a conceptual approach.

However, exploring the effectiveness of a developed MS Excel worksheet/system as a visually enhanced teaching method to grasp chemistry concepts in Sri Lanka is not extensive. In this research it was planned to develop an MS Excel worksheet /system as an interactive, visually enhanced quality input, the same was used for the instructional process in teaching chemical kinetics concepts in secondary level and it was compared with the traditional teaching method which was not broadly taken into consideration in the field of chemistry education in Sri Lanka. This study thus attempted to fill these existing research gaps by investigating the effectiveness of the system in teaching and learning of a selected segment of the G.C.E. A/L chemistry syllabi.

B. Methods

Developing an MS Excel worksheet/system to learn concepts in chemical kinetics

The development of worksheet/system was achieved using the inbuilt MS Excel functions with minor usage of visual basic in MS Excel. In this study it was used as a teaching aid which empowered the students to learn the concepts of chemical kinetics and compared it with the traditional teaching method. The spreadsheet program used was MS Excel 2013. Arrangement of the MS Excel system can be stated as; providing related theory as brief notes (based on the content given in the resource book which was published by National Institute of Education), graphs for zero order reactions, first order reactions, second order reactions, comparison of graphs of the three orders- variation of reaction rate over the concentration of the reactant, variation of concentration of the reactant over the time and the variation of log rate over log concentration and a practical component with guided questions. In the section of the practical a freely accessible video clip of the practical can be embedded to the system and used prior to the practical as a demonstration. Experimental determination of the effect of concentration on the rate of the reaction between sodium thiosulphate and nitric acid was selected, since it is one of the highlighted practical in the secondary chemistry syllabus, Sri Lanka. They are presented as combined worksheets in the system.

Table I summarizes the basic chemistry equations that were used to create the graphs on zero order reactions, first order reactions and second order reactions. Apart from them units of rate constants are mentioned in each section as numerical or graphical ideas become meaningless without the proper units.

Table. I Equations used in creating the graphs for the reaction of A → Products

Order of the reaction	Rate expression*
Zero order	Rate = k $[A]^0$
First order	Rate = k $[A]^1$
Second order	Rate = k $[A]^2$

* k = rate constant, [A] = concentration of the reactant A

The inbuilt functions in MS Excel permit users to test logical conditions and return a logical result in the form of text or numbers. Elementary logical functions available in MS Excel comprise AND, OR, NOT, TRUE, FALSE, IF, IFERROR *etc*. These were used appropriately along with the chart wizard for the purpose of generating interactive graphs. Active X controls such as command button, spin button and scroll bar (to change the rate constant and to change the order of the reaction) were used for zero order, first order, second order, comparisons and practical sections of the study.

Using the template created in teaching chemistry in a classroom setting

The experimental design used was a proxy pre-test post-test design [8], [9], [10]. This approach is very similar to the standard pre-test post-test control group design illuminating only one difference; the pre-test scores can be collected even after the treatment was administered since it is not the same paper given as the post-test. In this method a pre-test is not actually done but an alternative/ proxy technique is used to represent the first test. The content used in the post-test was based on the concepts presented in the chemical kinetics unit and the students did not have any previous knowledge or experience with the related chemical kinetics concepts before the study. Therefore, using the same post-test question paper as the pre-test to assess the equivalency between the two groups is futile. A meaningful alternative to the pre-test is the immediately previous term test to asses a newly introduced subject matter. The post- test was introduced just after the treatment in order to avoid any other means in which students gain the concepts regarding the chemical kinetics lessons.

A set of 30 students each who follow chemistry as a subject in Grade 13 (secondary level) were chosen as the sample and randomly divided into two groups (Group 1 and Group 2). Student's t-test at 95% confidence level was used to assess the similarity/homogeneity of the two groups before starting the lessons, taking their final term test chemistry performances into consideration [11]. The purpose of the study was explained clearly to the two groups and obtained their consent and commitment to support the study. Then the chemistry lessons were conducted to give the theoretical understanding regarding the rate law, order of the reaction, zero order reactions,

first order reactions, second order reactions, associated graphs *etc*. for both the groups using the same teacher. Students in Group 1 learnt using the adapted MS Excel worksheet approach in addition to the ordinary chalk and board method while the students in Group 2 experienced the same lessons using only the ordinary chalk and board method. At the end of the learning session, same question paper at the competency level similar to that of G.C.E. (A/L) was given to both the groups as the post-test. Answer scripts were assessed by the same examiner and the performances were evaluated by means of statistical test-student's t test.

3. Results, Discussions and Conclusions

A. Developing the teaching aid

A user-friendly application was developed. Guidelines are given so that a user who is working with this approach for the first time even can operate it smoothly. The definition of the rate constant and basis of changing it are given as a note, in which the user can see when click on the red colour arrows of the system. Students can observe the changes to the graphs instantaneously when the parameter set (k, rate constant) is being changed. Out of the six sections of the created quality input area of first order reactions with its usage are given below as an example.

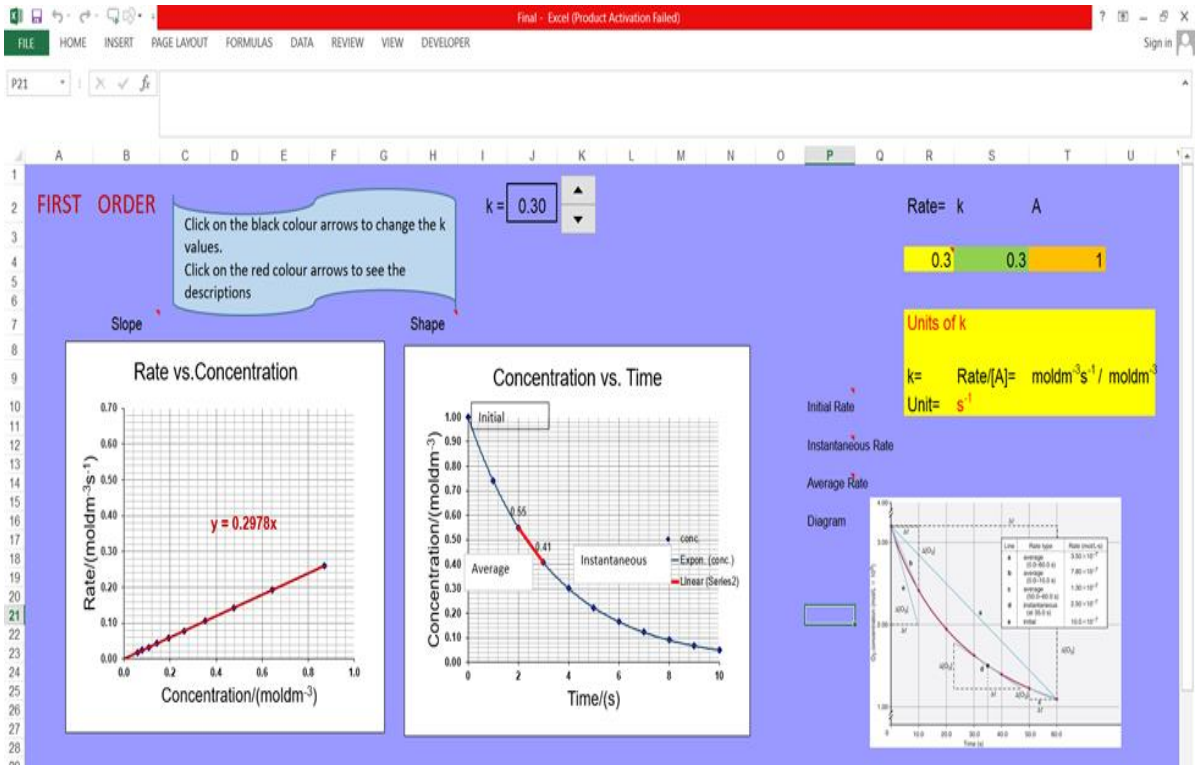

Fig. 2 Graphical representations for first order reactions

As mentioned earlier the graphs are interactive. The graph of rate versus concentration for the first order reaction is an upward-sloping line as the rate is directly proportional to the concentration of the reactant. The slope of the graph quantifies the rate constant, k and as rate constant varies the student can visualize the change in the slope and the rates corresponding to different concentrations *vice versa*. As shown, for the first order reaction, the variation of concentration over the time is a curve which indicates the decrease in reactant concentration with time. The units of the rate constants are introduced, Students were given the opportunity to exercise simple calculations associated with rate law which enables them to conceptualize the kinetics basics. The concepts of initial rate, instantaneous rate and average rate also can be introduced using the plot of concentration versus time quickly.

In the similar manner remaining sections are elaborated introducing theories involved, graphs of zero order reactions, second order reactions, comparison of the graphs among the reaction orders and a section for practical and associated problems.

B. Using the MS Excel worksheet in teaching chemical kinetics in a classroom setting.

The results of post-test corresponding to the two groups are given in Figure 3.

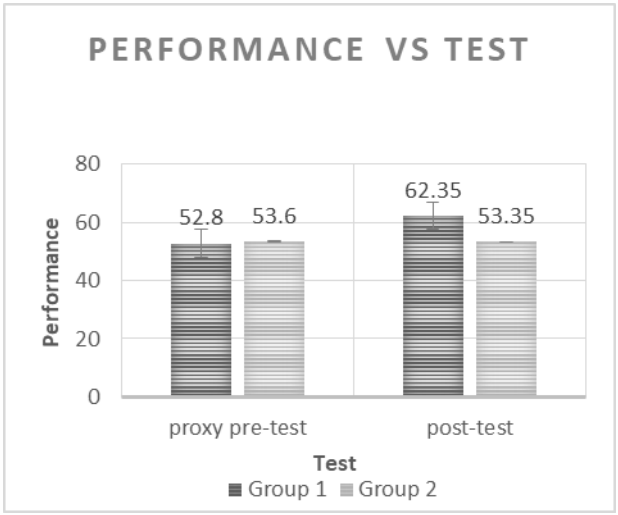

Fig.3 A column graph of mean for the two student groups based on the test type**.**

Figure 3 illustrates that both the students in Group 1 and 2 have similar academic performance at the proxy term test but there is a significant difference in the post-test results. For the proxy term-test, it was noted that $t_{calculated}$ (1.107) is lesser than the $t_{tabulated}$ (at 95% confidence level, 2.048) indicating that there is no significant difference between the mean values of the two groups. Thus, the knowledge levels of the two student groups are at the same qualifying to be used as a proxy pre-test. Since teaching method is the only variable in the experimental set up, any significant difference of the post-test results attributes to the differences of teaching learning practices of the two groups.

Table II Statistical data for t-test calculations

	Group 1	Group 2
Mean ($\bar{x}$)	$\bar{x}_1$ = 12.47	$\bar{x}_2$ = 10.67
Standard deviation (s)	s_1 =2.799	s_2 = 2.193
$(s)^2$	$(s_1)^2$= 7.838	$(s_2)^2$ =4.809
No: of students (n)	(n_1) = 15	(n_2) = 15

Statistical data for t-test calculation of the assessment marks are given in Table II. Equations used for student's t-test calculation are displayed as (1) and (2).

$$s_{pooled} = \sqrt{\frac{s_1^2(n_1-1)+s_2^2(n_2-1)}{n_1+n_2-2}} \qquad (1)$$

S_{pooled} = 0.475

$$t_{calculated} = \frac{|\bar{x_1}-\bar{x_2}|}{s_{pooled}}\sqrt{\frac{n_1 n_2}{n_1+n_2}} \qquad (2)$$

= 10.372

Mean value of the post-test of Group 1, shows a clear difference. For this, Group 1 mean value is higher than Group 2 mean value and is significantly different at 95% confidence level. Mean values for the post-test for Group 1 and Group 2 are 12.47 and 10.67 respectively (without any conversion). The $t_{calculated}$ for the mean values (10.372) is greater than the $t_{tabulated}$ (at 95% confidence level, 2.048) implying a significant difference of the two teaching methods according to student's t test at 95% confidence level. Thus, it clearly demonstrated that the developed MS Excel based teaching tools for conceptualizing the teaching of chemical kinetics is very effective compared to traditional method.

These results can be combined with the explanation of Dale's cone. Accordingly, students in Group 1 did the lessons with exhibits/with the application (visual receiving). They gained knowledge through 'see' and 'hear' both. This experience allows students to see the meaning and relevance of concepts based on the different pictures and representations presented. Here, they achieve the learning outcomes like demonstrate, apply and practice. The bottom of the Cone represents "focused experience" that is encountered by the senses of the body and which is highly effective for the learner. Since Group 1 learn through an interactive platform they are in a state of moving down in the Cone having "focused experience" as well. Students of Group 2 gained knowledge mostly through

hearing (verbal symbolic) only. The cone displays the average retention rate for various methods of teaching. Students tend to remember 50% of what they 'see and hear'. When the students were tested after the lesson Group 1 performed better as they understood better by a visually enhanced method.

C. Conclusion

A novel computer assisted, MS Excel application has been designed to teach chemical kinetics concepts allowing the students to gain better understanding of the lesson visually. It is a simple and user-friendly approach that can be used for secondary level students to explain basic concepts in chemical kinetics. The MS Excel application will allow the students to visualize theories such as rate law, order of the reaction, variation of graphs with their underpinning concepts, information which can be obtained from graphs and the practical aspect of chemical kinetics easily.

In order to study the effectiveness of the application in the teaching learning process, same chemistry lessons were taught to two groups of high school students; using the developed application as a teaching aid along with the traditional chalk and board method for one group and only through the chalk and board method for the other group. Mean marks of the group who were taught using the MS Excel application in addition to the chalk and board method was significantly higher at 95% confidence level using the student's t test.

As a consequence, it can be concluded that this proposed teaching aid, MS Excel worksheet improved the students' knowledge regarding chemical kinetics significantly than that of the traditional teaching method. The application together with the teacher's instructions given can be used by the students to achieve the competency level expected in chemical kinetics to secondary level students

This quality input would be useful for chemistry teachers and learners in their teaching learning process. Since this is a user-friendly application, students can use it a self-study material and a revision guide as well. These findings of the study would be an eye-opener for school administrators in order to improve the infrastructure necessary for such implement and also for policy makers when preparing curriculum upgrading and reforms.

Teaching Chemistry is not limited to the few methods that are used now but rather it is a broad concept that includes all the media that we can use to attain a balance as we facilitate effective and meaningful learning. Therefore, it is evident that MS Excel worksheet (system) created can be utilized to conduct chemistry lessons to the students in a more effective manner

References

1. Dale, E., "Building a learning environment". Bloomington, IN: Phi Delta Kappa Foundation, 1972.
2. Dale, E., Audiovisual methods in teaching, 3rd ed.. New York: Dryden Press, 1969.
3. Bharathy, J. B., "Importance of computer assisted teaching & learning methods for chemistry". Science Journal of Education, vol.3(4), pp.11-16, 2015.
4. Examination department, Chemistry Evaluation Report - G.C.E. (A.L.) Examination – 2016. Sri Lanka, Research and Development Branch, Ministry of education, Sri Lanka, 2016.
5. Zain, S. M., Rahman, N. A. and Chin, L. S.," The teaching and learning of chemical kinetics supported with MS Excel". Journal of Science and Mathematics Education in Southeast Asia, vol.36(1), pp. 65-85, 2013.
6. Akcay, H., Durmaz, A., Tuysuz, C. and Feyzioglu, B., "Effects of computer based learning on students' attitudes and achievements towards analytical chemistry". Turkish Online Journal of Educational Technology, vol.5(1), 2006.
7. Sinex, S. A., "Chemical spreadsheet investigations: Empowering student learning of concepts via camouflaged mathematical exploration". Using Computers in Chemical Education Newsletter, 2007.
8. Moore G., "An empirical test of design patterns for children's environments, People and the physical environment research". Wellington, New Zealand: Victoria University of Wellington, 1983.
9. Trochim W. and Donnelly J. P., "The research methods knowledge Base", 3rd ed, Mason, OH: Thomson Publishing, 2007.
10. Carbonell P., "Quasi and experimental research designs, Interdisciplinary review of research and development",vol. 1(1),pp. 5–11, 2012.
11. Harris, D.C., "Quantitative Chemical Analysis", 8th ed.; W.H.Freeman & Company: New York,pp. 73-78, 2010..