Science and Technology improvement strategies in a dwindling economy

Conference Paper · September 2020

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Abstract

Science and Technology form the bedrock of industrial and socio-economic developments of any nation. Although the entire world suffers economic down turn at some point in time, the case of developing and less developed countries is usually very dip. Such a state of dwindling economy as a result of decline in gross domestic product (GDP) for two or more consecutive quarters retards the progress and success of science and technology knowledge expansion at all levels given the very high costs of needed resources. The condition brings about system failure, limited access to and coverage, poor performance and achievement of students. This paper reports a three year study of how to practically improve the poor state of science and technology teaching and learning at the face of paucity of appropriate and adequate instructional materials, using a mixed grid improvised technologies (local and technological tools) for Chemistry and Physical sciences in South Africa. The study made use of 115 willing Chemistry and Physical science using an embed research design with a mixed method approach. The effects of the improvement strategies were determined and reported. As part of the findings, the teachers were found to have gained content knowledge, love for becoming more resourceful, increased dexterity in practical tasks that highly improved the performance and achievement of their students as measured by their improved matriculation results.

Introduction

The pillar of growth and economic and industrial well-being of a nation is pivoted on the strength of science and technology input and output of the country particularly in the 21st century. Ndirangua, Kathurib, & Mungaib (2003) reported the dire need for improvisation of teaching materials in Kenya as a result of government's choice to focus on teachers; salaries and increasing level of poverty in the country which consequently could not enable parents to effectively play the role of procuring teaching materials for the schools. Eminah, Taale & Raheem (2012) observed that the continuous shortage of teaching and instructional materials at the pre-university level is a source of great concern. This situation has well crept into the universities especially the public institutions in the recent times in the developing and less-developed countries. This situation becomes very glaring in such counties in Africa like Nigeria, South Africa and others which are experiencing dwindling and recessive economies.

In spite of the overwhelming increasing importance of Mathematics and science to humanity in this 21st century, many students are still disadvantaged in the subjects. This is shown in the poor quality of passes registered in the subjects at Matric levels each year by many of the students.

The annual pass rates of students at the National School Certificate (NSC) examinations have always been critically viewed and of great interest. Table 1 below presents a seven year period of Physical Science students results in two categories. The one is achievement at 30%

mark and above indicating that any learner able to score a total of 30% is deemed to have passed as it is in other subjects too. The second category is achievement at 40% mark and above, in which case a learner is deemed to have passed the examination with a minimum score of 40% and above. A close study of the Table shows that excepting the year 2010 with 47.8% of the 205364 students that wrote Physical Science passing at 30% mark and above, the rest six years that over 50% of the students that wrote the respective examinations passed. Following the arguments of several analysts (Department of Education, 2016), it is clear that the quality of students achievement at this level needs much to be desired.

The use of 40% mark and above to analyse the entire results looks more acceptable since it points to a more universal measure for quality of performance and achievement. However, Table 1 shows that less than 50% of those that wrote Physical science examinations passed in all the seven years considered.

Table 1: Seven Years (2010 – 2016) Physical Science NSC pass rate in South Africa

Year	No. that wrote	No. achieved at 30% and above	% achieved at 30% and above	No. achieved at 40% and above	% achieved at 40% and above
2010	205 364	98 260	47.8%	60 917	29.7%
2011	180 585	96 441	53.4%	61 109	33.8%
2012	179 194	109 918	61.3%	70 076	39.1%
2013	184 383	124 206	67.4%	78 677	42.7%
2014	167 997	103 348	61.5%	62 032	36.9%
2015	183 189	113 121	58.6%	69 699	36,1%
2016	192 618	119 427	62.0%	76 044	39.5%

Various factors have been put forward as the cause of students; persistent poor achievement in science, mathematics and technology subjects. They include: teachers` level of qualifications and subjects of specialization, teachers` teaching approaches, students` background (academic and socio-economic), learning environment, career choice (school, peer group and parental influences), teachers` attitudes and level of commitment, availability of equipment and facilities, and teachers` competency levels in the use of available material.

This a report of trying to mitigate the effects of the identified factors resulting in students' perennial low achievement in Physical sciences by developing and using a special Science Teacher Professional Development (STPD) programme to train teachers and equip them for higher productivity. It was to help update Mathematics, Science and Technology teachers in content and pedagogy issues based on my research findings of topics teachers and students find challenging. It was indeed to ensure students' higher pass rates with better quality performance at the Further Education and Training level in South African high schools particularly in a dwindling economy.

This study was designed in such a way to effectively reduce the influence of poor content knowledge level of the teachers, poor teaching methodologies, and unavailability of adequate instructional materials in the schools. The approach therefore integrate the use of improvised materials with commonly available technologies that students in their homes. It is my belief that with the use of technologies alone will rather make the students gradually loose some critical science process skills such as manipulative skill, some aspects of observation skill using the sense of smell and others which can be developed by using the actual or improvised materials.

Improvisation alone may not be able to solve the problem of making the teaching and learning of science at the face of inadequate materials in the schools in the 21st century when information and technology resources are now in the hands of almost everyone on the street.

Theoretical Framework:

Scientific (Declarative and Procedural) Memory and Improvisation theory

An integration of theories of declarative and procedural (scientific) memory and improvisation theories was used to generate a workable theoretical framework for the study. Moorman & Miner (1998) looking at correlates of improvisation explained bricolage as "making do with the materials at hand" and as a special skill in improvisation. Our environment all over provides lots of inexpensive materials coupled with the information technology products in almost every hand in the 21st century. Procedural memory that is attainable through continued involvement in any task could be automatic or unconsciously accessible and could be seen as being intuitive in nature. Procedural memory is further described as "motor memory" (Pressing, 1988) and it is a kind of tacit knowledge because it difficult to transfer such knowledge in written or verbal form to another individual. The level of procedural memory increases with level of continued coherent actions in improvisation and its applications by an individual. Whatever material that is to be improvised for use in teaching science is expected facilitate and demonstrate relevant scientific principles and facts, improvisation manipulative and some science process skills acquisition to the students.

The figure 1 below shows a diagrammatic representation of the theoretical framework of this research. The scientific improvisation is a process of generating instructional materials which are not available in a school laboratory but which are relevant and important to giving meaning and understanding of concepts and practical principles and facts to the students. The process involves identifying the scientific concept to be taught at a given level of knowledge, gathering useable but inexpensive objects such as plastics, papers, pieces of wood, metals, batteries, sand and stones as the case may be. The necessary declarative principles and content knowledge and the practical skill or action knowledge which the topic and the improvised material should provide to the students are determined based on the curricular objectives. Then several coherent actions such as assembling and producing the improvised the instructional material, test-running the use of the material and evaluating its appropriateness, are put in place. The proper use of the produced gadget to enhance the level of students' performance and achievement in the subject as if they have been taught with ready-made industrially produced and expensive materials, culminate in action coherence. The expected resultant effect of this approach is that the scientific memory of the students should have well improved.

While the students will have enhanced results through learning with inexpensive materials in the times of economic melt-down, the teachers involved in the improvisation process and appropriate use of the products become more resourceful, and adaptive prevailing economic realities. Furthermore, such teachers could become entrepreneurs with time contributing to the economy by possibly employing some others.

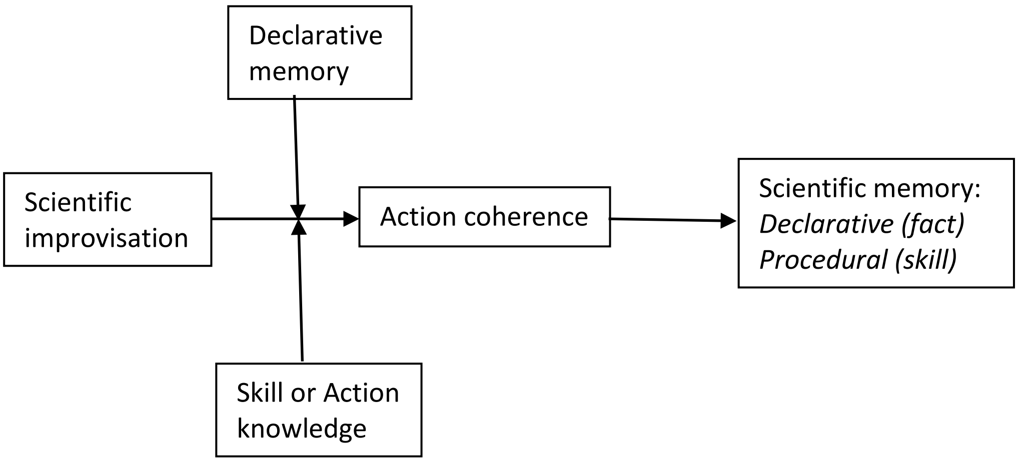

Figure 1: Theoretical framework of the project

Sample

The project was carried out with an average sample of 150 Physical science and Chemistry teachers who volunteered from both private and public high schools from Gauteng, North West, Mpumalanga and Limpopo provinces of South Africa. In effect, the sample was made up of an average of 50 teachers in each of the three years, 2014 to 2016.

Activities of the Project

The project ran in three phases each year of the three years from 2014 through to 2016. The phase 1 involved reaching out for permission from the district education departments in Tshwane municipality in Gauteng and Brits in North West provinces and their schools with the project flyers to solicit for volunteer Physical Science teachers that needed to enhance their content and pedagogical knowledge through the project. Teachers from Mpumalanga and Limpopo that participated in the project came by their friends' invitations. Records showed that over 7 and 4 teachers consistently participated in the project from Mpumalanga and Limpopo Provinces respectively while over 44 others came from Gauteng and North West Provinces. Teacher were requested to outline in a questionnaire, topics they find difficult to teach either for the lack of adequate content knowledge or deficiency in teaching methods or both and the topics were analyzed to generate a teaching curriculum for the project.

The phase 2 involved preparation of workshop materials based on the outcomes of phase 1 which were aligned to the requirements of the country's curriculum statement. Two research assistants were identified and recruited each year during the phase 2 with training in preparation for the actual workshop week termed phase 3.

The phase 3 usually ran for one week (Monday to Friday) during school holidays to give as many teachers as many teachers as possible the opportunity to always participate in the project. A pre-test was always given to the Monday of each project contact week every year of the three years. Materials to be used were usually arranged if readily available, or practical improvisation was carried involving the participants on that first day to generate the necessary improvised materials in addition to their smart phones, laptops and smart board. The main workshop was then facilitated with the research assistants playing one role or the other for four hours each day up to Friday and a post-test was administered on the participants. In all, there were three pre-tests (average of 50 participants each) and three post-tests in the same manner. A focus group interview discussion was carried out on six or the participants each year to further explore the perceptions about the research project and its impact. The topics facilitated during the entire project include: Mechanics; Electricity and magnetism; Doppler effect; Atomic structure; Periodic table; Chemical bonding, formulae and balancing of equations; Molecular shapes; Redox reactions; Chemical change and systems; and Organic chemistry as required by the South African Curriculum Assessment Policy Statement (CAPS).

Literature review

Motshekga's maths and science task team once reported that "Forty-three percent of South African grade five students failed to reach the lowest international benchmark". This means that such students have not yet mastered the basic reading skills required to access and retrieve information for reading comprehension purposes," (Progress in International Reading Literature Study (Pirls, 2013). The essence of the above discourse is to point to the dare need for training and retraining of science and technology teachers from the Foundation through General Education to Further Education and Training levels through projects such as one presented in this paper.

The Trends in International Mathematics and Science Study (TIMSS, 2011) showed that South African pupils have the lowest performance among all 21 middle-income countries that participated. Improvement, yet the county is one of those that performed poorly. The 2015 result showed a very narrow marginal. In the words of the Minister of Basic Education, Motshekga Angie, TIMSS 2015 results showed the country as having the "most improved education system in the world" because the country has recorded an impressive performance for the first time in the "advanced series of the international competition. The study is an international standardized test for mathematics and science. TIMSS examines the effectiveness of curriculum and instruction in relation to student achievement especially at grades 4 and 8. TIMSS has been administered every four years since 1995, and is sponsored by the International Association for the Evaluation of Educational Achievement (IEA) in Amsterdam. TIMSS Advanced was conducted in 1995, 2008, and 2015 (Goh, 2017a).

The need for any country to have and maintain science, mathematics and technology curricula comparable to the standardized world curriculum benchmark has become obvious, and to ensure that the means and machineries for successful implementation are put in place. Curriculum can be divided into four aspects: the *intended*, *enacted* (instructional events in the classroom), *assessed* (student achievement tests) and *learned/attained* (students` achievement in the tests) curriculum. The more aligned a national curriculum is to what is common across countries the greater the chance of that country's students performing well (Ndlovu & Mji, 2012). Countries such as Singapore, Korea, Japan, Russia and Hong Kong remain in the top 5 out of 38 countries including USA and the UK in the 2015 TIMSS competitions (Goh, 2017b) with enabling curricula. Such curricular should enable the students to: understand the world through problem-solving, observations and critical mathematical and scientific thinking; prepare for high school and future challenges since they are bound to meet with some standards in MST as they proceed to higher studies or join the labor market at graduation.

Marcelo (2014) presented an example from Amazonas on how the problem of low performance by students particularly from the rural areas was solved**.** The Amazonas State Secretariat of Education (SEDUC) in 2007 created the State On-site Technology-Mediated Instruction System (SEEPMT). The project "by 2011 had reached 25 percent of the 6,100 rural communities in Amazonas State, serving 26,000 students, 80 percent of whom were in secondary school" (Marcelo, 2014). Teachers teach their classes from the SEDUC Media Center in Manaus using technologies that provide real-time interactivity in video conferences, Internet access, content, and applications. This approach has proved to be economical and at the same time reaching to a large population at the same time with real educational experiences.

Teacher education must focus on developing teachers with an interactive pedagogy that promotes implementation of interactive teaching and learning with digital tools (Diallo, 2008). The use of interactive boards should therefore be developed and encouraged. However, a one-time South African Minister of Education, Professor Kader Asmal in 2003 said "The challenge of providing modern technologies to schools in order to enhance the quality of learning and teaching will require a significant investment." This statement points to the high cost of providing modern technologies in all schools at the time even though most schools may have theirs under lock and key with excuse of inadequate competent manpower to use them. DoE Government White Paper (2003) noted some challenges of ICT summarized into three broad areas, namely: participation in the information society; how ICT impacts on access, cost effectiveness and quality of education; and the way ICT is integrated into the learning and teaching process. In devising a way to mitigate the influence of the above stated factors, this project was carried out for three years using the integration of improvised materials and commonly used smart phones boards to provide content and pedagogical training to willing Physical science teachers.

Figure 2 below is an illustration of the necessary interactions between the teacher, student, learning task, teaching and learning styles and Web 2.0 interactive board.

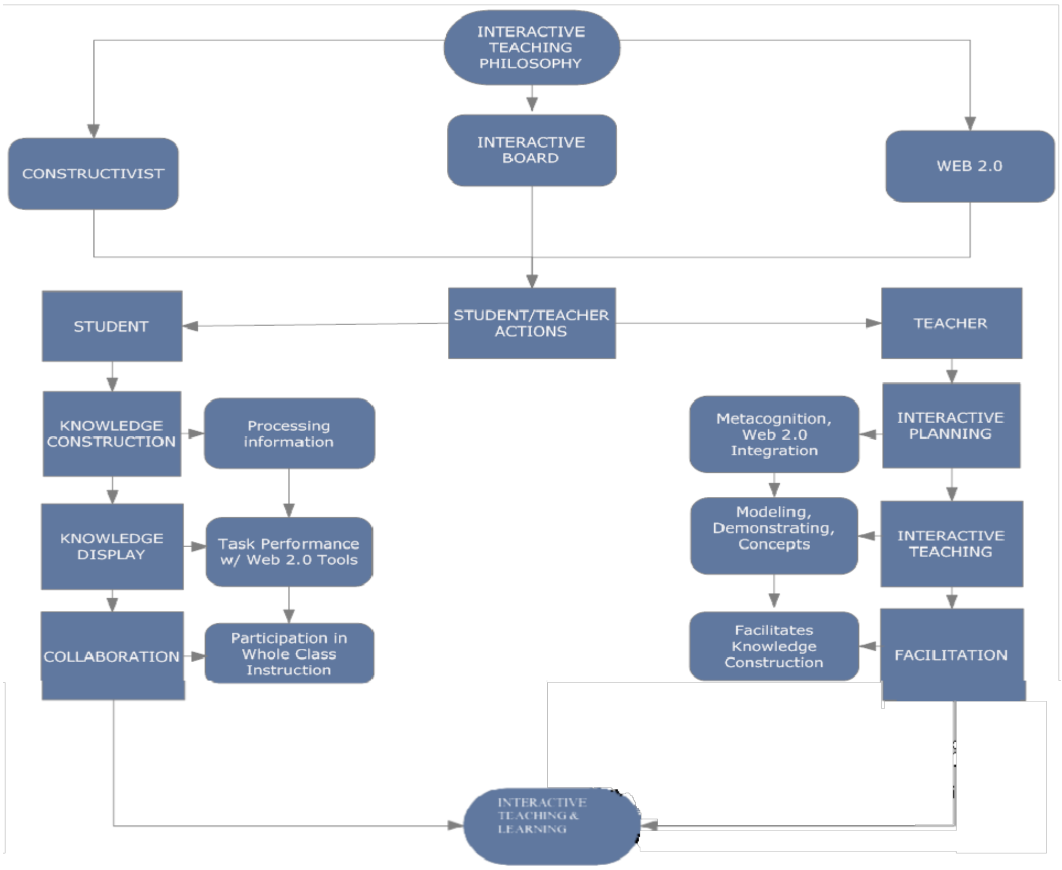

Figure 2: Components of the framework for interactive digital teaching approach.

Adapted from Diallo, S. (2008)

Web 2.0 technology is an improve form of the Web 1.0 as a shift from the usual teacher-centred mode of instruction to student-centred mode of instruction with so much other comparative advantages as shown in the Table below:

Differences between traditional and new technology enhanced instruction.

TRADITIONAL (Web 1.0)	**NEW (Web 2.0)**
Teacher-centered instruction	Student-centered instruction/learning
Single-sense stimulation	Multisensory stimulation Single-
path progression	Multipath progression Single-
media	Multimedia
Isolated work	Collaborative work

Information delivery Passive learning Reactive response Isolated, artificial context	Information exchange Active/exploratory/inquiry-based learning Proactive/planned response Authentic, real-world context

Web 2.0 tools and interactive boards are exemplary good pair. For instance, Interactive board is used to access Web-based tools such as tangram activities from the national library of virtual manipulative. Both the board and Web 2.0 readily assimilate classroom environments with interactive capabilities. Some top Web 2.0 Tools for Teachers are as follows:

Animoto…, Poll Everywhere, LibriVox. ..., Twitter. ..., Dropbox. ..., + 7. Wordpress and Bloogger..., Diigo. ..., Conceptboard making use of digital whiteboard ..., Prezi (this is a must-have tool for teaching presentations, this is one web 2.0 resource that really has changed the face of the classroom).

It should be observed teachers can take advantage of several free teaching tools which are accessible by the use of their mobile smart phones and tablets especially at times dwindling economy and inadequate or even unavailability of ready-made resources in schools. www.oppia.org/create for free teaching tool called "Easily create web-based lesson – oppia.org and many other sites provide very useful information in this regard.

Raising the participation and performance in science and technology subjects at the face of a dwindling economy remains a worthwhile venture for any progressive-minded nation. It will rather help to fast-track the improvement of the nation's gross domestic product (GDP) when necessary and result-oriented measures are taken. Such measures could include setting up or restructuring the school system as to have one Special Science School/Centre (Ochonogor, 1997; Reddy, 2006) in each senatorial or municipal district that is well equipped for progressive and meaningful teaching and learning of science and technology instead of littering every village and community with schools without functioning facilities and equipment. Furthermore, MST subjects should be made friendlier to the students by both teachers and authors, without any form of gender stereotyping in the language used in books and question papers (Ochonogor, 2006). There is a strong to integrate improvisation and its applications with using friendly and interactive educational technologies in the teaching/learning processes to enhance the expected science process skills of teachers and students. Teacher development should be seen as a continuum by all as a life-long learning process and teachers need to be encouraged to always have their eyes on INQUIRY process as a proven standard way of teaching science starting with OBSERVATION. Such approach will enable them explore ways to answer the: *What? How? Why?* of the learning and teaching task at hand.

Data Analysis

The pre-test and post-test scores were analyzed using descriptive statistics. This form of statistical analysis was favored because of how the sample of participants was composed.

Furthermore, the sample was also the same as the population because participants were requested to willingly join the project but not more than 50 each year. Table 2 below show that a total of 150(N) in-service teachers participated the project

Table 2: Variance and Standard Deviation Calculations for the Pre- and Post-test scores

Variance and Standard Deviation Calculations		
	Pre-Test	Post-Test
N:	150	150
M:	47.00	67.33
SS:	19070	17919.33
$\sigma^2 = SS/N$	127.13	119.46
$\sigma = \surd\, \sigma^2$	11.28	10.93

A significant mean difference of 20.33 can be established from the Table above in favor of the post-test post treatment scores. It further shows a higher explained variance (σ^2) for the pre-test scores and consequently a higher standard deviation (σ) than with the post-test scores. It is statistically interpreted that lower variance and standard deviation values connote the closeness of scores obtained in any test to the mean score. Such condition proves that more candidates have performed with improved scores compared to their pre-treatment scores. This is evident from the Appendix that shows the participant raw scores from both test.

Effect size of the sample of the project was also evaluated with the pre-test mean and standard deviation as from the control group in accordance with the requirements of effect size calculations. It was found out that the Cohen's *d* value of 1.83048 was exactly the same for Hedges' g and very slightly greater than Gates' *delta* of 1.802305. This is interpreted in this paper as a strong measure of the positive effect (Coe, 2002) of the project approach.

Analysis of the qualitative responses from the focus group interviews proved a strong agreement with the findings of from the quantitative data generated. A few of the responses are summarized here in this paper as the participants were asked to *describe their overall reflections about the project:* the participants said '*I made a good choice to be part of this project. I have gained from several angles of knowledge. Now, I can teach many Physical science topics with high confidence, I have learned more on contents of topics that used to be challenging to me and I am motivated to improvise materials not readily available to make* *my lessons more interesting, practical, …. Taking part in this project has helped me to tremendously improve my content and pedagogical knowledge, and I can now generate and use low cost improvised materials with commonly used technologies to enhance my science teaching.'*

Conclusion and implications

This project was undertaken with the general objective to determine ways of improving the teaching of science and technology subjects such as Physical sciences during a dwindling economy. Literature and research reports have always seen improvisation and use of technologies as two separate strategies for the teaching of science. It is my belief that these stand-alone strategies cannot produce meaningful science teaching and learning to the level of the 21st century science and technology expectations. A meaningful science teaching should positively influence all the needed scientific process skills and attitudes and should encourage some entrepreneurial skill developments among the students at all times. Such skills can be comprehensively acquired through proper integration of improvisation with commonly used smart phone and board. This underscores the choice of theories of declarative and procedural (scientific) memory and improvisation theory to generate the theoretical framework for the project. Major skills nurtured in this project include observation, manipulative, recording, analyzing, inferring and interpreting among others; pedagogical skills and science content or declarative knowledge at very minimal costs.

Recommendations

The outcomes of this three-year project point to its success according the participants who have joyfully been sending individual information on how the use of the project strategies is steadily improving their science teaching tasks with confidence. Effective improvement strategies for science are possible in sustainable long and short terms and should be by the Government, Teacher Training institutions, NGOs, Curriculum planners, Teachers and Examination authorities such as Departments and Ministries of Education. It is on the basis of this that the following recommendations are made to ensure a continued enhanced science and technology achievements by students even under a dwindling economy:

1. As a long term plan, the government needs to establish and effectively equip at least 3 special science high schools in each province with appropriate and qualified human resources. The government should supply, introduce interactive educational technologies in the teaching/learning processes in the special high schools and get the teachers trained in their uses (Training time is usually short).

2. The government needs to introduce and sustain science, technology and mathematics teachers` allowance as incentive to motivate teacher towards spending extra time for improvisation and sourcing of local materials to complement available materials in the schools.

3. Teachers must be made to teach subjects they adequate content knowledge and the pedagogy of teaching them. This will help to reduce the effect of poor and wrong foundation usually laid by using non-science to teach students at any level of the school system.

4. Training and re-training of mathematics and science teachers must be continuous based on standard and adequate contents.

5. Assessment questions given to students must be scientific and reasonable and NOT misleading as shown in the following examples:

   (a) An element is ……………..

   A. Is a pure substance made up of one type of atom?

   B. Is a loaf of bread?

   C. Is an animal that eats meat?

   D. Is an instrument used to measure books?

   (b) A pure substance is ……………

   A. Two or more different substances mixed together

   B. A substance made up of one particle throughout

   C. A class of boys and girls

   D. The universe

   (c) The first element on the periodic table is ……

   A. Hydrogen

   B. Copper

   C. Water

   D. Iron

Acknowledgement

I sincerely acknowledge the University of South Africa, Pretoria for granting me a research ethical clearance and space to run this very successful project.

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Appendix: Participants' Raw Scores (Copyright – the Author)

No. of Participants	Pre-Test Scores	Post-Test Scores
1	52	66
2	37	55
3	43	60
4	29	55
5	50	50
6	46	69
7	49	58
8	53	56
9	41	55
10	53	56
11	44	70
12	58	64
13	45	68
14	10	53
15	27	56
16	39	58
17	51	67
18	59	98
19	57	63
20	43	56
21	55	68
22	64	76
23	60	91
24	43	57
25	55	61

26	43	61
27	51	63
28	38	68
29	43	70
30	16	59
31	46	57
32	42	69
33	31	43
34	40	52
35	19	30
36	06	56
37	43	66
38	13	51
39	38	55
40	44	53
41	53	64
42	29	57
43	37	68
44	42	55
45	51	63
46	66	71
47	45	59
48	49	50
49	29	50
50	44	65
51	53	80
52	48	76
53	52	75
54	42	61

55	51	71
56	52	64
57	53	80
58	46	80
59	46	78
60	43	61
61	57	90
62	51	65
63	63	76
64	51	70
65	65	80
66	48	71
67	41	80
68	51	81
69	48	61
70	56	66
71	49	75
72	67	96
73	55	78
74	39	58
75	48	81
76	55	71
77	29	68
78	34	61
79	16	48
80	58	59
81	50	71
82	49	78
83	46	71

84	56	75
85	60	80
86	63	76
87	54	75
88	67	80
89	49	71
90	47	73
91	53	71
92	62	71
93	51	75
94	44	78
95	62	78
96	53	78
97	56	61
98	31	61
99	58	71
100	53	76
101	44	51
102	49	75
103	37	68
104	40	55
105	29	53
106	48	60
107	56	78
108	49	64
109	51	80
110	48	78
111	52	61
112	56	91

113	47	76
114	53	65
115	49	68
116	57	82
117	48	67
118	51	63
119	37	58
120	56	80
121	61	75
122	52	71
123	38	68
124	44	61
125	51	71
126	49	68
127	53	63
128	57	71
129	21	50
130	36	65
131	49	66
132	36	55
133	29	60
134	48	69
135	33	56
136	58	70
137	53	68
138	55	75
139	52	58
140	41	67
141	50	63

142	57	98
143	43	76
144	68	91
145	44	61
146	54	70
147	48	63
148	52	68
149	61	78
150	48	80