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Teaching human evolution: How a museum programme in the palaeosciences improved learner performance

The teaching of evolution at school level in South Africa was introduced in 2006. However, evolution remains a controversial aspect for school learners in South Africa, and many misconceptions persist among teachers and learners. The study described in this paper sought to investigate whether an interactive palaeosciences university-based museum programme (PUMP) would benefit the examination outcome of learners in human evolution in the Gauteng Province of South Africa. The PUMP made use of sociocultural theory and consisted of inquiry-based activities with casts of hominid skulls and pelvic bones. The Cultural-Historical Activity Theory (CHAT) framework was used as a theoretical framework. Pre- and post-tests were written, before and directly after the activities, and a provincial examination essay question was analysed to see if there was a difference in results between those who attended the PUMP and those who did not. Focus interviews were conducted with learners and teachers. The results of this study indicate that the understanding of human evolution increased following PUMP. This study advocates an inquiry-based approach to the teaching of evolution to learners, preferably at an informal science learning institution such as a museum.

Significance:

- Workshops increased Grade-12 learners' understanding of human evolution.
- The workshops improved the preliminary examination results of the Grade-12 learners.
- It is recommended that the teaching of human evolution to school learners be supplemented with visits to informal learning centres such as museums.

Introduction

South Africa has a rich fossil heritage.[1] However, when the teaching of palaeosciences was introduced into the school curriculum in 2006, it was met with resistance.[2] Learners and teachers have many misconceptions regarding the basic principles of biological evolution[3], and mistakes in South African school textbooks further perpetuate these misconceptions[4]. South Africans have some of the lowest rates of acceptance of human evolution[5], mostly because of conflicting religious views[6,7] and the use of standard forms of instruction[8] rather than interactive methods[9] such as inquiry-based techniques, application or analysis[10]. In this paper, we describe a study conducted with schools in the province of Gauteng and the Museum of the Evolutionary Studies Institute (ESI) at the University of the Witwatersrand, Johannesburg (Gauteng), South Africa. The study was launched in 2018 and was aimed at stimulating interest in the palaeosciences. In particular, we sought to investigate whether a palaeosciences university-based museum programme (PUMP) would benefit the examination outcome of learners. The study involved presenting the topic of human evolution as an interactive activity whilst Grade-12 learners from schools in one educational district in Gauteng visited the ESI museum.

Many have suggested that collaborations between schools and informal science learning (ISL) centres had a positive cognitive and affective outcome in school learners and that pedagogical research, where learning takes place in an informal setting, should be pursued.[11] For example, natural history museums often have an abundance of information on display[12] and inquiry-based activities are successful in helping learners to gain knowledge and meaning about the past[13]. Such visits encourage learners to 'see and think', thus exposing them to 'thinking skills' through guided conversation and questions asked by educators and learners. The new information is therefore gained through reasoning, inference and deduction, which enhance learning.[14] Sociocultural theory dictates that the interaction with peers, while engaged in an activity, as well as the scaffolding provided by educators, deepens the learning experience.[15,16] In the context of South Africa, studies of ISL centres have found that visits by learners improved learning[17], with pre- and post-visit sessions by teachers assisting to reinforce an informal learning experience[18].

Study design

We used a mixed-methods approach.[19] Data were collected through pre- and post-tests, examination scripts, observations, focus interviews as well as semi-structured interviews.[20] Purposeful stratified sampling[21] was chosen. In this type of sampling, the population used in a study is divided by the researcher based on specific characteristics. Then, random sampling is used to represent each subgroup. South Africa has different types of schools, and for this study, two different types of schools were selected: former model-C schools and township schools. Former model-C schools are usually well resourced and perform well[22], whereas township schools are usually located in under-resourced communities. The sample used in this study was composed of a total of 13 schools, represented by former model-C (6) as well as township (7) schools.

CHAT as a theoretical framework

The study was guided by the third-generation Cultural-Historical Activity Theory (CHAT)[23], which links educational theory and practice[24,25]. CHAT acts as a lens through which research is viewed, and intermediate theories are filters when analysing data.[26] The intermediate theories used in this study were sociocultural theory[27] and community of practice[28]. According to Foot[29], CHAT is composed of six components. The first component is the subject, the individual or group that performs an activity together to obtain an object or outcome, which is the second component of the activity system. The activity is modified by the cultural and historical influences of the community of the activity system. The third component is the community, which is made up of people who have an interest in the same common object and who participate in the activity system. This temporary activity system exists only while the university and schools are busy with the activity.[30] Tools, the fourth component, are used by the subject to achieve the object of the activity system, and could be conceptual or material. The tools are shaped by the needs, values and norms of the culture of the activity system. Rules, the fifth component, regulate the actions of the subject towards the object and community. The university had its own rules and division of labour, while the schools had their own. Sometimes this led to contradictions in the system. The last and sixth component is the division of labour, which relates to the horizontal division of tasks and the vertical division of power, resources and access. The activity system is dynamic and continuously evolving through collective actions.[31] Hence, the object is dynamic.[32] The activity theory was further developed into a system with two interacting activity systems with a shared object.[33] This system is known as the third-generation CHAT. According to Engeström and Sannino[34], the internal contradictions within the activity systems drive transformation within the activity systems. The contradictions within and between two activity systems, working on the same object, could be compared. Contradictions are the central driving force of change and development in CHAT[35], which are structural tensions within and between activity systems that emerge due to historical developments, systemic mismatches or conflicting motives. More recently, Engeström and Sanino[34] developed the fourth-generation CHAT, which focuses on networks of activity systems rather than just interactions between two systems. It emphasises dialogicality, polyphony (multiple voices) and distributed agency in expansive learning, incorporating globalisation, digital technologies and sociopolitical complexities, highlighting how multiple, interconnected activity systems co-evolve through negotiation and boundary-crossing. Fourth-generation CHAT seeks to address challenges such as global crises, digital transformation and power dynamics by examining how diverse activity systems interact at a broader scale.

We used the third-generation CHAT framework[25,36] to investigate the influence of the PUMP on the performance of Grade-12 learners in human evolution in one educational district in the Gauteng Province, South Africa (Figure 1). We also investigated the learners' views on evolution, as well as the community of practice between the different communities and learners' views on the PUMP. One of the contradictions of the activity system was the feedback from school principals during the first year that field trips to the university-based museum were costly and impacted teaching time for the final exit examinations.[20] This led to a second activity centre where PUMP was taken to schools. Hence, the first activity system is concerned with PUMP at the university-based museum, while the second system is concerned with PUMP at schools. The subject (S) of this activity system is the Grade-12 learners who attended the PUMP. These learners came from schools within one educational district. Second, the community (C) of this activity system consists of the university lecturer (IJM) and assistants, the district Life Sciences Subject Advisor (GvW), teachers and principals of the schools. Third, the rules (R) that govern the activity system are the rules of the university, that of the schools, and the rules and regulations of the Gauteng Department of Education (GDE) when learners go on field trips. Fourth, the tools (T) of this system are sociocultural theory, inquiry-based learning, the nature of science, the university laboratory with fossils and fossil replicas, the museum and the worksheet that the learners completed. Fifth, the division of labour (D) was between the university lecturer (IJM) and assistants, the Subject Advisor (GvW) and the teachers. Sixth, the object (O) of this activity system was to teach human evolution to Grade-12 learners in an effective way to improve their performance. This paper focuses on one of the aspects of CHAT, namely the object.

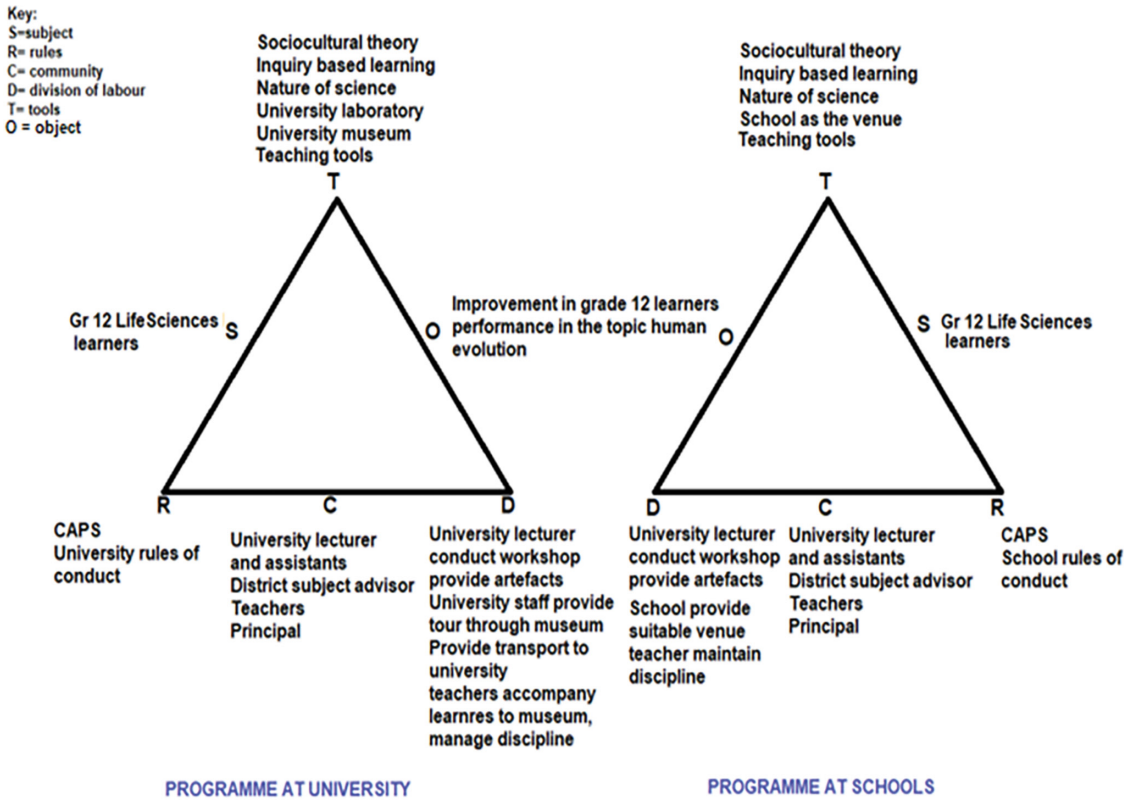

Figure 1: The third-generation Cultural-Historical Activity Theory (CHAT) design used for this study.

PUMP

The National Diagnostic Report on learner performance on the National Senior Certificate examinations[37-39], released by the South African Department of Basic Education, identifies common errors and misconceptions of learners. The PUMP aimed to address these common errors and misconceptions in human evolution.[20] The PUMP started at the University of the Witwatersrand with a tour of the palaeontology museum and fossil preparatory division. For the museum part of the study, the PUMP included a worksheet that had instructions for a treasure hunt. Learners were briefed before they started and were then given an hour and a half to search for the different clues in the museum. Afterwards, a feedback session was held with the learners. Thereafter, the learners went to the fossil preparation laboratory where they viewed the extraction of fossils. Lastly, they were exposed to inquiry-based human evolution activities. They had to observe, infer, predict and reach a conclusion.[40] For this purpose, the learners had to follow the instructions on the worksheet and investigate artefacts. They measured cast skulls of different primates (*Gorilla gorilla, Pan troglodytes, Australopithecus africanus, Australopithecus sediba, Homo naledi, Homo erectus* and *Homo sapiens*), observing and making inferences about skull features such as the size of brow ridges, prognathous, dentition, palate shape, the position of the foramen magnum and cranial ridges. Then the learners, working in groups, had to use their data, compare these skulls and place them in an evolutionary sequence from *Gorilla gorilla* to *Homo sapiens*. Further, pelvic bones of three species/genera (*Pan troglodytes, Australopithecus* and *Homo sapiens*) were compared to decide which were bipedal, quadrupedal or a transitional species/genus. The three types of stone tools were real artefacts that the learners had to study (Olduvai, Acheulian and Middle Stone Age). The university lecturer scaffolded their learning by discussing each one at the beginning of the workshop, indicating how sophisticated they were.[40] The sophistication of the tools was linked to cranium size and cognitive development. Learners then had to decide which species of hominin was most likely to produce each stone tool. Moreover, they had to analyse mutations in shortened DNA sequence fragments of six different species and decide who had the most in common. After this, they had to draw a phylogenetic tree using the information they generated during the workshop. During the activity, at least one mentor was moving between groups and helping the learners.[40] Learners had to make inferences at the end of the session which were discussed during the feedback session. Based on input from school principals during the first year of the programme which indicated financial constraints, schools did not visit the university-based museum during the second year of the study. Instead, the university-based museum conducted the inquiry-based activities of the PUMP at schools during the afternoons. The same schools participated during the first and second years of the study.

The learners also wrote pre- and post-tests, which contained the same five questions on human evolution. The pre- and post-tests were piloted on two groups of learners. No questions were left out by any learner during the pilot, and the timing for the tests was found to be adequate. The pre-tests were also checked for questions that were too easy, and there were no questions that were correctly answered by all the learners. Content validity[41] is the degree to which questions are representative of all the possible questions that could be asked. Test-retest reliability[42] was used to check reliability, with reliable instruments delivering scores that are stable and consistent. The test score should be nearly the same when the test is administered at different times. This study ran over 2 years and multiple groups of learners were tested. The values stayed consistent. The statistical significance of the data was obtained by calculating the *p*-value using the two-tailed t-test. The *p*-value indicates the probability that the data was obtained randomly. A critical value (α) of 0.05, which is the value typically chosen by statisticians[43], was selected and a *p*-value smaller than this indicates statistical significance as there is only a 5% chance of the null hypothesis being accepted. The reason for using a two-tailed *t*-test was that one group of people was tested at a different time, and the sample group was greater than 30.[42] The pre- and post-test also had a question in which learners were asked whether humans evolved from other species of animals.

Observational notes were taken and video clips and photos were analysed. Observations were made regarding each learner's involvement, whether they asked for assistance, and whether and how they participated in the feedback session. The observational notes were coded inductively and themes were generated. After the workshop, four to six volunteers were asked to participate in a focused interview. They were asked what they enjoyed, what they did not enjoy and if they thought humans evolved from animals. The interview notes were transcribed and coded inductively. Themes were generated which were triangulated with the themes obtained from the observations. Semi-structured interviews were conducted with the teachers and school principals. The teachers were asked what their view was of the workshop. Principals were asked about the logistical impact of the workshop on their school and if they supported learners participating in field trips to informal learning centres. Interviews were also held with museum educators. The researcher and outreach staff reflected on how the PUMP changed over time as a result of feedback from learners, teachers and subject advisors via feedback from the pre- and post-tests, interviews and observations, and whether the changes had had a positive impact on learners' cognitive, affective and formal academic performance, as well as the participation of the teachers.

The provincial preliminary examination of Gauteng during the first year of the study contained an essay question that addressed human evolution. The question expected learners to describe the characteristics of the skull of *Homo sapiens* that differentiate them from African apes. Learners had to explain how the differences between the human skeleton and that of African apes result in different modes of locomotion. The following year, the principals of schools in the educational district were asked for permission to analyse the essay question in the question papers. A total of 13 schools still had the scripts available. The group that attended PUMP had a sample size of 246 learners and consisted of five township schools and three former model-C schools. The group that did not attend PUMP had a sample size of 323 learners and consisted of four township schools and one former model-C school. The data from the preliminary examinations were compared using an unpaired two-tailed *t*-test because two different groups of people were used.

Permission for the study was obtained from the University of the Witwatersrand (HRECN18-04-017), the GDE and the ESI. Learners had to give assent while their parents, teachers and school principals provided consent to be part of the study.[20]

Results

Pre- and post-tests

Overall, 687 learners completed both the pre- and post-tests. The highest score for the tests was 7 marks. The results indicated that the performance of the learners improved from the pre-test to the post-test (Table 1), showing the value of the PUMP. The *t*-test indicated that the difference was statistically extremely significant ($p<0.0001$, 95%, $t = 23.7825$, df = 686, standard error of difference = 0.078). The 95% confidence interval (CI) of [–1.68,–1.43] indicated that there was a 95% certainty that the confidence interval contained the true mean of the population. The standard error of the mean (SEM), which evaluates how closely the sample estimates the population, was small, also indicating a more precise estimate.[44] When we compared the university with the school-based PUMP (Table 2), the results were similar, indicating that the location of the programme did not affect the outcomes of the pre- and post-tests. The *t*-test values for the university-based workshop were $p < 0.0001$, 95%, $t = 18.1862$, df = 330, standard error of difference = 0.088, with a 95% CI of [–1.77, –1.43]. For the school-based workshops it was $p < 0.0001$, 95%, $t = 13.3043$ df = 276, standard error of difference = 0.110, with a 95% CI of [–1.67, –1.24]. Regarding the question of whether humans evolved from animals, 41% of learners agreed or strongly agreed in the pre-test and this increased to 51% in the post-test. In the pre-test, 26% of the learners neither agreed nor disagreed, and this decreased to 6% in the post-test.

Observations and interviews

Using the answers from all the sources (the interviews at the university museum, at the different schools, and the post-test, $n = 714$ with some

learners selecting more than one option), the results indicate four themes obtained from learners on their views of the workshop, supporting the finding that the workshops were beneficial to learners:

- 60% of the learners found the workshop beneficial, learnt new facts and gained a deeper understanding of human evolution.
- 25% of learners found the workshop enjoyable, exciting and interesting.
- 20% of learners found the hands-on workshop with good explanations better than a lecture or using textbooks.
- Only 8% of learners did not enjoy the workshop, got confused, or felt that the school was not a suitable venue.

The benefits of the workshop, as expressed by learners, were also echoed by the interviewed teachers ($n = 10$ with some teachers selecting more than one option). All the teachers thought the workshop and the hands-on activities were beneficial to the learners. Most of the teachers (90%) referred to the fact that the learners could link what they saw in the workshop to the theory taught at school. Half of the teachers indicated that the learners could refer to the workshop when they were studying for the exams because the learners also took photos of the artefacts. Moreover, 40% of the teachers said the workshop was very educational, and that the lecturer was knowledgeable and able to answer all the questions of the learners. They also found the mediation that he provided in the groups during activities very beneficial. Three teachers indicated that the workshop would help the learners with the exams and that the analytical skills used in the workshop were beneficial. Five teachers were interviewed a year after the workshop, and they were asked whether they saw a difference between the groups that attended the workshop and the groups that did not attend the workshop. All the teachers agreed that the learners who attended understood human evolution better than the ones who did not attend the workshop. In this regard, the learners who attended were better able to visualise the content than the learners who had used only textbooks. The taking of pictures by learners seemed to have helped. One teacher was interviewed on how the workshop at the university differed from the workshop at school. In this case, the learners attended the workshop at the university three years prior and now the workshop was conducted at the school. The teacher responded that while the workshop was beneficial and educational, it was easier to conduct the workshop at school, but some of the enjoyment was lost.

The two types of workshops had their benefits and drawbacks. At the university, the late arrival of the buses negatively affected the workshops; some learners were ill-disciplined and bothered the other university staff; too few teachers joined the school groups, leaving the education team to deal with discipline; bus strikes caused the dates to change; learners missed out on a day of schooling in other subjects; and extramural activities at schools caused learners to leave early. However, the learners were very enthusiastic and energetic, and they enjoyed being in a different environment. The afternoon school-based workshop was more convenient for the schools, but the learners seemed tired and hungry because they had attended a whole day of normal schooling, which required more effort to keep them focused during the feedback session. As a result, the workshop duration was shortened. The learners also did not have the benefit of seeing the fossil laboratory and museum.[45]

Preliminary examinations

The schools that attended the PUMP obtained higher marks for the examination question (out of a total of 20 marks) on human evolution, compared to those schools that did not attend (Table 3). An unpaired *t*-test found that the difference was extremely statistically significant ($p < 0.0001$, 95%, $t = 10.9467$, df = 567, standard error of difference = 0.362). The SEM values were small, which indicated a more precise estimate. However, the average scores remained below 50%.

Discussion and conclusion

The outcome of CHAT indicates that the knowledge of learners about human evolution improved after attending the PUMP. The success of this workshop highlights the value of the tools in this activity centre, namely inquiry-based learning, sociocultural theory as well as working with fossils and replicas. Based on a sociocultural theoretical perspective, effective learning is most likely to take place where learners work in groups, solving problems and handling objects under the guidance of an experienced facilitator.[16] Furthermore, it enables active participation in the learning process to obtain ownership of the process[46] and develop curiosity, interest and a desire to learn[47]. It is recommended that inquiry-based activities, rather than teacher-centred methods, should be used to enhance the scientific understanding of human evolution by learners.[20] The degree of conceptual change could be linked to the degree of active learning.[48] Through this process, observation and communication skills will be enhanced, thus allowing learners to connect previously obtained knowledge and experiences to new concepts.

Table 1: The pre- and post-test results of 687 learners

Test	Mean score	Minimum score	Maximum score	Standard deviation	Standard error of the mean
Pre-test	2.74	0	7	1.31	0.05
Post-test	4.29	0	7	1.55	0.06

Table 2: Comparison of the pre-test and post-test data between the university- and school-based palaeosciences university-based museum programme (PUMP)

	University-based PUMP		School-based PUMP	
	Mean	Standard deviation	Mean	Standard deviation
Pre-test	2.84	1.21	2.69	1.45
Post-test	4.44	1.49	4.15	1.65

Table 3: Comparison of examination result between the schools that attended the palaeosciences university-based museum programme (PUMP) and those that did not

Groups	Sample size	Mean	Minimum	Maximum	SD	SEM
Attended	246	8.20	0	18	3.99	0.25
Did not attend	323	4.24	0	20	4.48	0.25

Teachers often do not have the time, experience or the necessary skills to design these types of learner activities.[49] The learners who participated in the study indicated that the university lecturer explained the content well, and some even felt that it was better than a lesson from their teacher at school.[20] This finding is supported by Connealy[45], who indicated that staff at ISL centres often possessed more in-depth knowledge about some subjects than teachers. For this reason, it is recommended that learners should be taken to a relevant ISL centre to experience these types of interactions. According to Hutson and colleagues[50], a field trip with a single focus would likely impact the cognitive skills, knowledge, interests and future careers of learners. They found this to be particularly true for academically challenged learners. Field trips provided opportunities to create connections which would help with understanding classroom concepts and developing an enjoyment of learning and skills.[15,51,52] The teachers in the study indicated that learners who were usually troublesome were surprised by their interest and willingness to participate in the PUMP.[20] Whitesell[52] found that it was most effective for relatively disadvantaged learners and that it could be an important tool for closing gaps in racial and socio-economic achievement in science. The pre- and post-tests used in this study showed that learner performance in both advantaged and disadvantaged schools improved after attending the PUMP. Moreover, those learners who attended the PUMP also performed better in their essay question on human evolution in the preliminary examinations, compared with those learners who did not attend the workshop. As a result, this collaboration with a university-based museum had a positive outcome on the performance of learners in human evolution.

The workshop increased the acceptance of evolution from 41% ($n = 595$) to 51% following the workshop, even though it was not the purpose of the study to increase the acceptance of human evolution, but rather to improve the understanding of the topic. This increase could be attributed to the hands-on approach of the workshops, in which learners could observe, measure and analyse various aspects, applying analytical techniques. Moreover, facilitation of the workshop by an expert in evolution enhanced the experience. In this regard, Sutherland and L'Abbie[7] note that "Even though an acceptance of evolution is positively correlated with understanding evolution, it is not necessary. A person can understand evolutionary theory without accepting it as true." Teachers still have poor content knowledge concerning human evolution[52] and religion and the non-acceptance of evolution is a stumbling block which hinders the understanding of evolution by teachers[7]. ISLs are valuable tools to address these shortcomings in teacher knowledge as their professional development is positively influenced by visits to these centres. However, all the teachers in this study taught the topic in the required detail and did not have any objections to the teaching of the topic. They seemed happy to be part of the programme, as they felt that they also learnt something new about human evolution. Hence, the workshop also assisted teachers in addressing their misconceptions or understanding of human evolution.[20]

Currently, not all schools in Gauteng can attend programmes such as the PUMP, and the university staff cannot visit all the schools. To overcome this challenge, several interventions can be considered. For example, Life Sciences teachers must receive training on the content, as well as the pedagogy of teaching human evolution. Common misconceptions of teachers can be identified through surveys, and intervention workshops should be planned around these misconceptions. Teachers in South Africa still have poor content knowledge concerning human evolution.[52] Given the complex nature of evolution[8], there are many misconceptions regarding evolution and that learners find evolution challenging[7]. The GDE currently has a teacher professional development programme offering free training, which can be used for such a purpose. Moreover, ISL centres in Gauteng offer exhibitions on human evolution and fossils (e.g. at the University of the Witwatersrand, the Ditsong National Museum of Natural History, Maropeng, Sterkfontein Caves and the Sci-Bono Discovery Centre). It is recommended that the GDE annually promotes school visits to these places.

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Data availability

All the data supporting the results of this study are included in the article itself.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical clearance for the study was obtained from the University of the Witwatersrand's Human Research Ethics Committee (HRECN18-04-017). Permission to conduct the study was obtained from the Gauteng Department of Education and the ESI granted permission for use of their premises.

Authors' contributions

G.v.W.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management, funding acquisition. S.B.: Data analysis, writing – the initial draft, writing – revisions, student supervision. Both authors read and approved the final manuscript.

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