Influence of guided inquiry on first-year students' attitudes to laboratory activities and performance in physics

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Abstract. This paper reports on the effect of Socratic questioning integrated with guided-inquiry (GI) on students' attitudes to physics laboratory activities and academic performance. Ninety seven first-year Bachelor of Science physics students participated in this study at a well-established South African university. The students were assigned systematically to control (C) and experimental (E) groups. The C group did recipe-based practical activities, while the E group did GI practical activities. At the end of the semester, data were collected using the written practical and hands-on examinations, follow-up focus group interviews as well as the theory examinations. Results indicated that the E group outperformed the C group in certain questions, but also performed worse in most of the questions. Overall, there were differences between the C and E groups, however the differences were not statistically significant. We conclude that GI laboratory activities did not enhance first-year physics students' academic performance. It was also found that, the E group students developed a positive attitude towards the GI practical activities, while the C group students appreciated the procedural approach followed in their recipe-based practical activities. The results of this study however, contribute to the understanding of current science laboratory practices, learning processes and the potential effects of inquiry-based instruction at university level.

1. Introduction

Inquiry-Based Science Education (IBSE) is encouraged by science education reform documents [1, 2, 3]. IBSE is believed to enhance the deep understanding of scientific inquiry (SI) process skills and science literacy [4]. It is believed that engaging students in SI can assist them in applying their critical and creative skills when performing scientific investigations, using observations and inferences to formulate empirically based explanations [1]. Integrating guiding questions in inquiry-based activities may direct students' thinking and help teachers to understand students' thinking [5]. The teaching approach was based on Socrates' use of questioning to assist a student to think, analyze and seek for new information [6]. Learning Physics is considered to be about constructing knowledge on the basis of experimentation and reasoning, rather than memorizing facts [7, 8]. The current study posits that the GI physics laboratory activities may bring about changes in students' thinking and problem-solving skills [9].

The current paper reports on part of a study that was undertaken at a South African university to investigate whether changing some of the first year university physics traditional laboratory activities into GI format may influence students' attitudes towards laboratory work and performance in physics

[7]. The rationale behind this transformation was that the previous practice of doing the traditional practical laboratory activities was procedural [10] which, according to research, does not enhance students' thinking skills [11]. The aim of this paper is to examine if the combination of guiding questions and GI physics laboratory activities would help students develop positive attitudes towards laboratory work as well as developing a better academic performance. This paper addresses the following research question: *To what extent does GI based instruction in laboratory practical activities as compared to traditional recipe based laboratory practical activities influence first-year university students' attitudes towards laboratory work and performance in physics?* The results of this study may enhance the understanding of current science laboratory practices, learning processes and the potential effects of inquiry-based instruction at university level.

2. Literature review

2.1. Inquiry
Inquiry has a plethora of meanings, however it is broadly described as scientific investigations that encourage classroom practices like posing questions which focus at knowledge attainment and development [12]. The design of the GI laboratory practical activities was informed by McDermott and the Physics Education Group's [13] Physics by Inquiry (PbI) model. The critical component of PbI curriculum is the use of guiding questions where students are encouraged to work in small groups and guided through step-by-step questions when performing activities. According to social constructivist learning theory, effective learning occurs when teachers and students collaboratively work together to co-generate knowledge through investigations, posing questions and finding solutions [14, 15].

2.2. Inquiry-based Instruction versus Traditional Instruction
Inquiry-based teaching approaches use a range of teaching strategies that involve a student as an active agent in the knowledge construction rather than passive recipient of information [16]. Inquiry encourages student-centred approaches and uses instructional practices such as observations, formulating questions, realising gaps in one's knowledge base and conducting investigations to close the gaps. Traditional teaching approaches promote transmission of researched knowledge to students, while student centred approaches like inquiry inspire students to construct knowledge by engaging in investigative activities. Additionally, it is believed that learning by conducting investigations is conducive to students understanding of how knowledge is generated [17]. Inquiry-based teaching helps students to use a deep approach to learning whereas the traditional teaching method encourages students to use a superficial approach [18].

2.3. Role of guiding questions in academic performance in physics
Arons [7] argued that the use of Socratic questioning may assist students to shift from declarative to operational knowledge. Declarative knowledge is knowledge that can be stated and operational knowledge is knowledge that can be applied (through a series of operations) [7]. Utilization of Socratic questioning and students' experiences may guide students to a superior understanding of scientific knowledge, reasoning abilities and logical thinking skills [19]. Syh-Jong's [20] study on the effectiveness of talking and writing in a collaborative environment showed that students do not only defend their science conceptions but also incorporate other students' ideas in clarifying their understanding. In another study, Crouch, Watkins, Fagen and Mazur [21] employed Peer Instruction (PI) which is a teaching approach of guiding all students in the learning process using structured questions for more than ten years in the introductory Physics at Harvard University. It was found in this study that PI promoted students' conceptual reasoning and quantitative problem solving skills.

3. Methodology

The current study followed an experimental design using a mixed methods approach [22], located within the post-positivist paradigm. Post-positivism allowed the researcher to explore the cause and effect of GI laboratory activities on students' academic performance [23] as well as to understand how multiple realities are created and maintained by participants in their personal views of physics knowledge [22]. All 220 Bachelor of Science students (132 males and 88 females) registered for the calculus-based introductory physics course were invited to participate, but only 97 students gave written consent and were systematically assigned to either the C or the E groups. Participation was voluntary and students could withdraw at any time. The C group performed the traditional recipe-based laboratory activities, while the E group performed GI laboratory activities. The physics practical laboratory activities conducted during the session served as a background context for the physics content [24] and the intervention programme lasted for eight weeks.

All groups of students performed the same recipe-based practical activities during the first semester. However, during the second semester, the C group performed the recipe-based laboratory activities following recipe-based instructions while the E group did GI laboratory activities following GI instructions. The GI and the recipe-based practical activities covered essentially the same physics content and used identical equipment. Care was taken to ensure that any questions asked had been sufficiently covered by both C and E groups.

The combined practical examination (i.e. the written and hands-on practical examination) was administered at the end of the term. The marking of combined practical examination and theory examination was done by laboratory assistants and lecturers respectively as in previous years. The quantitative results were analyzed statistically by the researcher to compare the performance of students doing either recipe-based or GI practical activities

Following the practical examination, focus group interviews were conducted to validate the data found through the combined practical examination. All students were invited by e-mail, only sixteen students (9 females and 7 males) responded and were interviewed by the researcher. No incentives were offered. Nine were from the C group while the other seven students were from the E group. There were three unstructured focus group interviews comprised of two groups of five students and one group of six students, where each interview lasted for an hour. In this paper, we will focus specifically on the questions probing the attitudes students had towards the laboratory work (questions 1, 2 and 5). The interviews were transcribed in full in a text file and transcriptions were analyzed following the guidelines by Lesh and Lehrer [25], that is, transcriptions were read several times, refined as meaning became clear, coded and analyzed for differences in students' experiences of C and E groups.

4. Results and discussions

4.1. Focus group interviews

Examples of students' answers during the interviews conducted at the end of the term are shown in Table 1. As can be seen from the responses to question 1, students in the E group (students C and D) could see the advantage of GI laboratory practical activities over recipe based activities. They felt that the practical activities were not difficult and that the practical activities aided their understanding and gave them more confidence in applying physics principles and they enjoyed the more interactive nature of the experiments.

Interestingly, the students in the C group (students A and B) who performed recipe-based practical activities felt that clear guiding instructions were essential, which suggests that these students enjoyed the step-by-step procedures when conducting practical activities. From the answers to question 2 it was clear that students in the E group (students G and H) enjoyed the challenge of GI activities. This may be an indication that GI gives students an opportunity to grow and overcome the need for recipe-like instructions, while students in the control group appreciated recipe based instructions simply

Table 2 Average scores in percentage point (pp) of the C and E groups in individual questions of the combined practical examination and theory examination

Short summary of question	Average score (%)		
	C	E	E-C (pp)
Combined practical examination (Written and hands-on)	64	62	-2
Written section of practical examination	60	56	-4
Hands-on section of practical examination	74	74	0
Theory examination mark	56	59	3

because they had no other experiences. Interestingly, student F in the C group realized that he would learn better if he were challenged to find a solution instead of just given the answer. In question 5, both groups expressed the view that the practical activities exposed them to new situations and contributed to their understanding of the application of physics to real experiments. It was observed that although students who performed recipe-based practical activities felt the need for guiding instructions, the students in the E group demonstrated a shift in their views about learning, confidence and thinking skills and came to appreciate the GI-based practical activities.

4.2. Practical and theory examination

From Table 2 it can be seen that the C group performed 4 pp better than the E group in the written practical examination, while there was no difference in the hands-on practical examination. In the theory examination mark, the E group performed 3 pp better than the C group. These differences are not statistically significant, and the results suggest that the GI laboratory practical activities had a very small negative effect on students' performance in the combined practical examination and a very small effect on the performance of students in the theory examination. It was also observed that E group students performing the GI practical activities took longer to do the same experiment when compared to C group students, as GI promotes a deeper level of understanding in contrast to the traditional model that promotes surface learning [2].

5. Conclusion

The study was designed to investigate whether GI activities would significantly enhance academic performance and attitudes to practical activities. It was found that the GI laboratory practical activities had only a very small effect on performance in the combined practical examination and the theory examination. We argue that the GI physics laboratory activities in this study did not result in a measureable enhanced performance, because theory examination in the current study did not focus on testing conceptual understanding and scientific process. Similar to the current study there are numerous studies that found that inquiry based activities do not improve academic performance. Research studies conducted by El-Nemr [26] and Lott [27] have shown that inquiry-based approaches had a small positive effect on students' academic achievement in examinations.

The E group students developed a positive attitude towards the GI practical activities, while the C group students appreciated the procedural approach followed in their recipe-based practical activities. This is in agreement with the findings in other studies that have demonstrated that Problem Based Learning provided a thought-provoking, encouraging and enjoyable approach to learning and promoted better attitudes and thinking skills in students [28].

The results of this study should not be generalized to first–year physics students' across South Africa or other countries. It is possible that some physics concepts may have been better addressed than others by the selection of the GI activities, though not by intention. It is therefore recommended that further research be undertaken to shed more light on how students' understanding of certain physics concepts are enhanced by GI activities. In conclusion, we believe that the insight gained in this study may guide transforming undergraduate science courses and may contribute to understanding of

Table 1: Examples of students' views expressed during the focus group interviews.

Interview questions	Group	Response
1. How did you experience the practical activities in general?	C	Student A: "The important thing we have done as you start the practicals you get your information sheet. And then it will describe how you will set up the equipment and that was very important part. Because you give that much preparation about terminology, about the practical you are going to do beforehand. But unless all those instructions for setting up the equipment were clear, all the preparation will mean nothing." Student B: "They were fine for me because we got instructions and we knew basically the outline of practicals. So we knew what to do sort of most of them but then as she said if you don't know the work behind the practicals then you became bit sketchy. There was also a chance to realise how much you know of your work at the time that u can study further for upcoming examinations."
	E	Student C: "Okay, basically the practical activities were fine not difficult but they actually exposed us to variety of physics things that we did not know about before. Like, the apparatus we were using during the practicals and some other physics concepts that we actually learnt in class. But we didn't know how to apply; we were actually given chance to actually see the application of those physics concepts during the practicals. Like for example, connecting those circuits. We only knew how to draw the circuit but didn't actually know how to connect what materials until we do the physics practicals." Student D: "I enjoyed the practical sessions this semester (second semester). They were much easier than last semester's practicals (first semester's practicals). Although the format wasn't very much different, the practicals were just easier. And also when we covered the work in the lectures, we had already done some of the practicals that were related to the classroom's theory content."
2. Would you prefer more guidance in the practical activity or more opportunity to investigate in your own way?	C	Student E: "I think that, the thing is, it really made it easier to relate to the theory and the fact that practical did not take that much preparation. I think that was nice because the thing is like we do not have time to spend hours and hours to prepare for something. And then the fact that usually we were preparing for an hour may be for the practicals and it was not that hard. You can actually like see how everything is coming together. You can see the full picture when doing the practicals, because they made it easier to understand the topic and they made it easier to write test because like if you forgot something, you can think ohh what did we do in a practical and you could actually make a comeback from that." Student F: "I agree with that because there is a thing like if you actually have to struggle to get something right you are going to remember like what you got wrong and what you got right on your own. Whereas if you get guidelines you are going to forget because it is just like a routine, just listen and repeat. You won't like make some conclusions on your own it will be somebody's work on your paper. I think that is repeating the same thing over and over again."
	E	Student G: "I would prefer to investigate on my own, so that I figure out things on my own. Because when you are guided you just follow the procedure but then at the end of the day you acquire less knowledge than when you do things on your own and see what is going on, like individually." Student H: "It is also nice (the one where you are given more opportunity to investigate on your own) because it actually make you think of what you are doing and giving the thing of like challenging yourself, like okay maybe if I do this and then maybe it will work. If I do this let us just see what happens on my own. And if you felt like then you just can't, you can ask the demonstrator to come and help."
5. Do you think the practical activities influenced your views in this regard?	C	Student J: I do not think like my view changed about science but I think it really got enhanced. And I felt more certain about what I felt about science because the thing is like now being able to prove staff and being able to see the law in front you like you see it actually hands on. You actually experience like that is happening, that is the truth and that makes you comfortable with science. And interacting with it because I think some people might escape because it so much info that you do not know where to like take a word or what to leave because you are so scared that there is so much laws such that you need to memorise. But now after like doing all the practicals, I think it really enhanced the fact that I now believe in laws when I see them on paper. So when something is now given I will actually believe more than I used to.
	E	Student K: Yes, well I think the practicals did demonstrate what we were learning about in theory or what we know in theory. So that when we see things in the real world, we understand how it all fits together, what is actually going on behind the bigger main concept."

the perceptions of science held by undergraduates, assisting university lecturers to improve scientific literacy in future scientists and diverse university graduates.

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References

[1] Department of Education 2012 Curriculum and Assessment Policy Statement: Physical Sciences (Grade 10 – 12) (Pretoria: Government Printer)
[2] National Research Council 2012 A Framework for K-12 Science Education *practices, cross-cutting concepts, and core ideas* (Washington, DC: National Academy Press)
[3] Next Generation Science Standards Consortium of Lead States 2013 Next generation science standards: By states, for states (Washington, DC: National Academies Press)
[4] Laugksch R C 2000 *Sci. Educ*. **84** 71
[5] Clough M P 2007 *Iowa. Sci. Teach. J.* **34** 2
[6] Crockett C 2004 *Educ. Leadership.* **61** 34
[7] Arons A 1993 *Phys. Teach.* **31** 278
[8] Clough M P and Olson J K 2008 *Sci. Educ.***17** 143
[9] McDermott L C, Heron P R L, Shaffer P S and Stetzer M R 2006 *Am. J. Phys.* **74** 763
[10] Banchi H and Bell R 2008 *Sci. Child.* **2** 26
[11] McDermott L C 1993 *Am. J. Phys.* **61** 295
[12] Blanchard M R, Southerland S A and Granger E M 2008 *Sci. Teach. Educ.* **93** 322
[13] McDermott L C and the Physics Education Group at the University of Washington 1996 *Physics by Inquiry, Vols. I and II* (New York, NY: John Wiley & Sons Inc)
[14] Vygotsky L S 1978 *Mind in society The development of higher psychological processes* (Cambridge, MA: Harvard University Press)
[15] Kruckeberg R 2006 *Sci. & Educ.* **15** 1
[16] Loyens S M M, Rikers M J P and Schmidt H G 2007 *Eur. J. Psychol. Educ.***22** 179
[17] Gibbs G 1988 Learning by Doing: A Guide to Teaching and Learning Methods (London, UK: Further Education Unit)
[18] Brew A and Boud D 1995 *High Educ.***29** 261
[19] Hake R R 2004 *The Arons-Advocated Method* [Electronic Version]. Retrieved on July 8, 2008 from http://physics.indiana.edu/~hake/AronsAdvMeth-8.pdf
[20] Syh-Jong J 2007 *Educ. Res.* **49** 65
[21] Crouch C, Watkins J, Fagen A and Mazur E 2007 *Research -Based Reform of University Physics* **1** 40
[22] Creswell J W 2009 Research Design: Qualitative, Quantitative and Mixed Methods Approaches 3rd Ed (Thousand Oaks, CA: Sage)
[23] Hesse-Biber S N and Leavy P 2011 The Practice of Qualitative Research 2nd Ed (SAGE Publications, Inc)
[24] Khishfe R and Abd-El-Khalick F 2002 *J. Res. Sci. Teach.* **39** 551
[25] Lesh R and Lehrer R 2000 Iterative refinement cycles for videotape analyses of conceptual change In R Lesh (Ed.) *Handbook of research data design in mathematics and science education* (Mahwah, NJ: Lawrence Erblaum Associates) pp. 665–708
[26] El-Nemr M 1980 A Meta-Analysis of the Outcomes of Teaching Biology as Inquiry (Doctoral Dissertation, University of Colorado, 1979), Dissertation Abstracts International, 40, 5812A. (University Microfilms International No 80-11274).
[27] Lott G *J. Res. Sci. Teach.* **20** 437
[28] Bonwell C C and Eison J A 1991 *Active Learning: Creating Excitement in the Classroom* (Washington, DC: ASHE-ERIC)