Differentiated pedagogy in diverse physical science classrooms

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Abstract

This study, located within Bernstein's sociology of pedagogy and the notion of 'opportunities to learn', commenced with the key question: what opportunities to learn physical science are made available in previously advantaged and disadvantaged South African classroom contexts? Data were collected through classroom observations and video recording of consecutive lessons on the same topic in the three schools. Data analysis showed that opportunities to learn the epistemology of science ranged from technical to specialised meaning realised by differentiated pedagogic modalities based within differentiated school contexts. Key influencing factors included differences in objective aspects like resource availability and class size with concomitant differences in discursive practices such as: pacing of knowledge; explicit evaluative judgement; social relations; and levels of knowledge and cognitive process taught. Different combinations contributed to differentiated opportunities to learn and understand science. The varying impact of class size on discursive practices is described and explained. We conclude that notwithstanding curriculum policy goals of equity in quality of learning experiences, actual opportunities to learn physical science are profoundly unequal. How the state intervenes to regulate these contextually specific inequalities in ways that gives fair chances to those trapped in lower socio-economic groups must be addressed as a matter of social justice.

Introduction

During apartheid, science education, like education generally, was stratified along both race and class lines. The education provided was racially separate and unequal. The apartheid state managed a centralised curriculum policy that was "racist, eurocentred, sexist, authoritarian, prescriptive, unchanging, context blind and discriminatory" (Jansen, 1999, p.4). Resources were very unequally distributed with ten times more spent per White child than per African child. By the 1970s, teachers were trained in racially separate colleges and universities (Sayed, 2004). Each type of college and university trained teachers of different races for schools of different races. The quality of teacher education for Africans was deliberately inferior to that for Whites. These structural inequalities made sure that high quality science education was not provided for the majority of Black, Coloured and Indian learners (Kahn, 2006). Describing science education more than forty years ago under Bantu Education, Horrel noted that children "gain little or no conception of basic principles" and "as few practical experiments are undertaken . . .the pupils fail to develop the ability to reason, to solve problems, and to draw correct conclusions from their own observations" (1968, p.72).

Democratic change in 1994 provided the basis for curriculum transformation and development. The new constitution (1996) and the Manifesto on Values, Education and Democracy (2001) stipulate the principles of human rights, democracy, social justice, equity, non-racism, non-sexism, redress, and ubuntu (DoE, 2003) establishes basic education, and equal access to educational institutions as the right of all citizens. A priority in new curriculum policy is equity or the provision of *"essentially the same quality of learning opportunities for all citizens"* (NDOE, 1997, p.21).

Based on the new constitutional goals, national curriculum policy advocates a high knowledge, high skills curriculum as the means for promoting social justice, equity and development. The generic seven critical cross-field outcomes that underpin all curricula (NDOE, 2003) require learners to go beyond recall, recognition and reproduction of information and to critically evaluate, analyse, synthesize, produce and apply knowledge.

The South African National Curriculum Statement (NCS) for Physical Science (2003) emphasises 'high knowledge and high skills', and 'progression' as core principles underpinning the curriculum. The Statement defines progression as a "process of developing increasingly advanced and complex knowledge and skills" (p.3). In keeping with the outcomes-based approach adopted for South African education, the NCS for Physical Science advocates the development of three outcomes. Each of these outcomes and progression within them is outlined below:

> Learning outcome (LO) one focuses on the development of practical scientific enquiry and problem-solving skills. "Progression in this outcome is reflected in the differentiation of the problem situation, as it moves from routine problem-solving skills to high-order problem solving skills."
>
> Learning outcome two requires that learners are able to construct and apply scientific knowledge. "Progression in this outcome is reflected by the increase in the quantity and depth of understanding of concepts used, together with an increasing understanding of the connections between different concepts in order to develop a well-organised knowledge base."

> Learning outcome three requires that learners are able to understand the nature of science and its relationships to technology, society and the environment. "Progression in this learning outcome entails the relationship between knowledge systems and claims, and the increasing ability to analyse and evaluate their impact on socio-economic development in the wider world." (NCS Physical Science, 2003, p.28).

In alignment with the generic critical outcomes the learning outcomes for physical science require learners to be provided opportunities to learn factual, conceptual, (LO2) procedural (LO1) and metacognitive knowledge (LO3). The cognitive processes advocated include progress from routine problem-solving skills to high-order problem solving skills. Learning outcome two requires that learners understand more concepts in depth as well as the connections between different concepts in order to develop a well-organised knowledge base.

But, policy is not practice, and from the perspective of curriculum as a contextualised social practice (Cornbleth, 1990), the aim of this investigation was to analyse the opportunities to learn (OTL) physical science in previously advantaged and disadvantaged schools and classrooms. The notion of OTL is underpinned by the assumption that a major cause of inequalities in student academic performance is inequalities in content taught, in quality of instruction, in time allocated to subject areas, in adequate institutional resources and in assessment practices. More important, however, is that these inequalities in OTL are not random nor neutral, but related to race, class and gender power relations.

SA writers on curriculum practices have argued that school contexts differ markedly, that the social class of the school (Hoadley, 2007) and that the status of the school as previously advantaged and disadvantaged (Harley and Wedekind, 2005) is a key determinant in the reproduction of social inequalities. Reddy (2005) argues that schools are not serving the majority of learners in the country equitably. She makes two pertinent points. Firstly, that "presently access . . . to better learning opportunities is determined by access to economic resources", that "individuals who have the financial resources to access schools from other ex-racial departments have a better chance for improved learning opportunities, improved performance and hence life prospects". Secondly that "the learners who live in poorer areas and receive fewer educational experiences from other sources, and who are particularly dependent on the school, are not receiving sufficient inputs from these institutions to improve their life chances" .

In this study we analyse the variations in opportunities to learn physical science in diverging classrooms in schools which are representative of the contexts that Reddy describes, with a view to establishing new insights about how the teaching of science differs in the schools in the post-apartheid dispensation.

Theoretical framework

This research based fundamentally on Bernstein's (1996, 2000) theory of pedagogic discourse also employs the notion of opportunities to learn (OTL). According to Bernstein, what is missing from cultural reproduction theories "is a conceptualization of the structural conditions and the discursive rules of pedagogy that generate practices of inclusion and exclusion" (Singh and Luke, 1996, p.1). In the class stratified British context the key differentiating structural conditions refer to different social class schools. The impact of the type of school attended on learners' performance in SA has been highlighted by Christie (2008) who cites the Teese and Posselwel (2003) study in Australia. The salient point being that children, who attend 'fortified schools', are better placed to meet the demands of the curriculum than children who attend 'exposed schools'. Fortified schools are schools serving rich communities that have concentrations of material and symbolic advantage, such as learners from higher economic status backgrounds, well-trained teachers, particularly in mathematics and physics, well-stocked libraries, extensive electronic data resources, smaller classes, remedial teachers and counsellors whereas exposed schools are schools that serve poor communities and are characterised by multiple disadvantages such as fragmented family lives, poverty, low levels of parental education, and lack of facilities in facing the demands of the curriculum.

With regard to 'discursive rules of pedagogy' Bernstein argued that one important cause of poor performance of working class children lies in the differences in the recontextualisation of knowledge into pedagogic communication in different social class schools – recontextualizaion being the transformation of knowledge into pedagogic communication in the classroom. Hence, "it is the structure of pedagogic discourse, the logic of this discourse, which provides the means whereby external power relations can be carried by it" (Bernstein, 1996, p.19). One could expect significant variations in pedagogic communication in fortified and exposed schools.

Amongst the conceptual tools provided for analysis of pedagogic discourse are the concepts of classification and framing. The concept classification refers to the boundary distinguishing forms of knowledge.

> Classification refers to the strength of the boundary between knowledge contents. Where classification is strong, contents are well insulated from each other by strong boundaries. Where classification is weak there is reduced insulation between contents for the boundaries between contents are weak or blurred (Bernstein, 1996, p.56).

Bernstein developed the concept framing to analyse the control relations demonstrated in the pedagogical relationship. Frame refers to the form of the context in which knowledge is transmitted or received. There are two systems of rules regulated by framing – rules of the social order and rules of the discursive order. The rules of the social order are referred to as regulative discourse and the rules of the discursive order as instructional discourse. With reference to the instructional discourse framing does not refer to the content of knowledge that is framed but to who controls the framing. According to Bernstein:

> Frame refers to the strength of the boundary between what may be transmitted and what may not be transmitted. Where framing is strong there is a sharp boundary, where it is weak a blurred boundary between what may and may not be transmitted (Bernstein, 1971, p.55).

Framing of the instructional discourse refers to the nature of control over the selection of knowledge (who decides what is valid knowledge and what isn't?); the sequencing of knowledge (who decides what is taught first, second, etc.); the pacing of knowledge (who decides the rate of transmission or how time is used?); and the criteria of assessment (who decides on valid acquisition of knowledge?). In the pedagogic relationship strong framing refers to explicit control by the teacher and weak framing refers to the arrangement where learners are given some control over knowledge. Thus, Bernstein clarifies:

> . . .where framing is strong, the transmitter has explicit control over selection, sequence, pacing, criteria and the social base. Where framing is weak, the acquirer has more *apparent* control (1996, p.27).

Furthermore, the elements of framing may vary independently, i.e. one could identify strong sequencing and weak pacing in the same classroom or other combinations.

The regulative discourse is a discourse of order in the classroom that regulates how knowledge is transmitted. The regulative discourse maybe positional or hierarchical where order is maintained by the teacher only and sourced from the teachers position as a teacher or personalised where order is maintained by both teacher and learners and achieved through mutual respect between teacher and learners (Bernstein, 1996).

In addition to analysing the classification and framing of knowledge we analyse variations in the complexity of knowledge and cognitive processes being taught. Hence, Bloom's (1956) taxonomy of educational objectives for the cognitive domain, and more particularly a contemporary revision of the taxonomy proposed by Anderson, Krathwohl, Airasian, Cruikshank, Mayer, Pintrich, Raths and Wittrock (2001) was recruited. The four levels of knowledge are factual, conceptual, procedural and metacognitive knowledge. Factual knowledge refers to the basic elements that learners must know to be acquainted with a discipline or solve problems in it. Conceptual knowledge refers to the interrelationships among the basic elements within a larger structure that enable them to function together. Procedural knowledge refers to how to do something, methods of enquiry, and criteria for using skills, algorithms, techniques, and methods. Metacognitive knowledge refers to knowledge of cognition in general as well as awareness and knowledge of one's own cognition. The six levels of cognitive processes are remember, understand, apply, analyse, evaluate and create. Remember refers to retrieving relevant knowledge from memory. Understand refers to determining the meaning of instructional messages, including oral, written and graphic communication. Apply refers to carrying out or using a procedure in a give situation. Analyze refers to breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose. Evaluate refers to making judgements based on criteria and standards and create refers to putting elements together to form a novel, coherent whole or making an original product (Anderson *et al.,* 2002).

Like the original taxonomy, the revised taxonomy is assumed to have a hierarchical nature, in that a more advanced level subsumes the levels below it. For example, it can be assumed that a person operating at the application level has mastered the cognitive demands required for working at the remember and understand level.[1]

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[1] Recognition that Bloom's original taxonomy did not sufficiently recognise the two-dimensional nature of knowledge led to its revision. The major change in the revised version has been to separate the knowledge dimension from the cognitive process dimension. The knowledge dimension is described as consisting of four levels, each level representing a different form of knowledge. Likewise, the process dimension consists of six levels, each level representing more demanding and complex cognitive processes.

The next section deals with the operationalisation of these concepts for data collection and analysis.

Operationalization of theory

Three public schools that were previously advantaged or disadvantaged were purposively selected as research sites so that the impact of their 'structural conditions' on pedagogic discourse could be analysed.

Description of research sites

School A[2], an ex-HOA school, is located in a well-established middle-class suburb in the city. During the apartheid era it catered exclusively for white learners, but was one of the first schools in the city to begin admitting learners of colour when changes in the political landscape were anticipated. Its learner population was racially and sexually diverse. It is well-maintained, well-resourced, well-managed and staffed by well qualified teachers. The school draws its learners mostly from the middle SES population from across the city. The majority of learners are transported to school by private transport. The higher school fee of R7 800 per learner per year ensures that more affluent learners are enrolled. The learner population was 40 per cent White, 25 per cent African, 25 per cent Indian and 10 per cent Coloured. The teaching staff was 70 per cent White and 30 per cent non-white. The language of instruction was English and competency in English was a requirement for admission to the school. In 2006 (the year this data was collected), the matriculation (Grade 12 school-leaving) examination pass rate was 100 per cent. There were 1 200 learners in the school, and 28 learners in the Grade 10 physical science class that was observed. The physical science teacher studied for a secondary teacher's diploma majoring in physics and chemistry at a teacher training college. He has taught physical science at Grade 10, 11 and 12 level for thirteen years, the last eleven at this school. The classroom was a science laboratory supplied with the necessary fittings with the laboratory tables serviced by a gas supply, a water supply, and an electrical supply. There was a fume cupboard, extensive storage cupboards and a preparation room. Teaching aids included an overhead projector, television and video sets, and various

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2 Fictitious names have been used to protect the identity of schools and teachers who participated in the study.

posters on the walls, including a large, highly visible periodic table. Each learner had his/her own science textbook. The teacher had a wide variety of textbooks and other resource books stacked on his table and in one corner of the classroom. The teacher was supported by a laboratory technician. This school resembled a fortified school closely.

School B, an ex-HOD school, was located in what was classified during the apartheid dispensation a residential area for the Indian population. It is about 10km from the centre of town. The area now has a mixed population of Indians and Africans, with African learners in the majority. The school is located in a very poor part of the area, and is surrounded by informal settlements as well as houses originally built by the town council for lower income Indian families. The school drew some of its learners from the surrounding communities, and many from township areas some distance away from the school. The learner population was 60 per cent African and 40 per cent Indian. The teaching staff was 90 per cent Indian, and 10 per cent African. The language of instruction was English. Learners had varying abilities to communicate competently in English. African learners who lived further away in other townships, travel to school using public transport like buses and mini-bus taxis, often having to take one trip to the centre of town, and then another from there to the school, incurring substantial transport costs. The parents of these learners chose to send their children to this school because they perceive it to offer better opportunities for learning than the schools in their own areas. School fees at the school are set at R900.00 per year. The matriculation pass rate in the year of data collection was 100 per cent. There were 1 125 learners in the school, and 38 learners in the Grade 10 class observed. The school had the basic infrastructure, was relatively well maintained and had basic resources to support teaching and learning. The physical science teacher completed a Bachelor’s degree with chemistry and physics as major subjects and then a Higher Diploma in Education. He had taught the subject for more than fifteen years. The classroom was a science laboratory supplied with water, gas and electricity. It was resourced with an overhead projector and has laboratory equipment to support practical work. The walls had a variety of science related posters on them, with a large periodic table on one side of the classroom. There was a set of textbooks for the learners to use, as well as reference books for the teacher. We described this school as a less fortified school.

School C, an ex-DET school, is located in a Black township (residential areas designated for Blacks during the apartheid era) close to the city centre. During those years it catered exclusively for African learners who lived in the township. Although the racial desegregation of schools has been effected, all learners were African. The teaching staff was 90 per cent African, 5 per cent Indian and 5 per cent white. While isiZulu was the mother tongue of most of the learners in the school, the language of instruction was English. Learners had varying English communication skills. The teacher sometimes used code-switching during teaching. The school drew its learners from the surrounding township, which mostly consisted of either unemployed or working class families. There was a high degree of unemployment in the area with many homes relying on state grants for survival. Parents were required to contribute school fees of R200.00 per learner per year. The school was poorly resourced and was impacted on by adverse social conditions which existed in the surrounding community. Its matriculation pass rate was 44 per cent. There were over 1 000 learners in the school and 24 learners in the class that was observed. The physical science teacher is well qualified to teach the subject, having completed a Bachelor of Science degree and Higher Diploma in Education. These subject qualifications are further supplemented by Bachelor of Education (Honours) and Master of Education degrees. He had taught the subject for more than fifteen years. The classroom was a science laboratory which was in a poor state of repair. It had minimal laboratory equipment to support practical work. There was a storage room attached to the classroom. The gas and water supply were not functional, sinks were broken, and many of the cupboard doors were missing. There was a small periodic table on the wall at the back of the classroom, but no other posters or charts. This school resembled an exposed school.

In order to analyse the ‘internal structure of pedagogic discourse’ Bernstein’s concepts of classification and framing have been employed. The classification of physical science knowledge in each lesson was analysed according to the following analytical framework:

Table 1: Classification of physical science

Element	Classification strength	Variation
C^{+}	Only science content knowledge was taught.	Strong classification
$C^{+/-}$	Science content knowledge as well as other forms of knowledge was taught.	↓
C^{-}	Science content knowledge was not taught Other forms of knowledge were taught.	Weak classification

The framing of physical science or the instructional discourse communicated was analysed according to the following analytical framework:

Table 2: Framing of physical science

Element	Framing strength		Variation
Selection of knowledge	F^{+}	During the learning activity, the teacher selects knowledge.	Strong framing
	$F^{+/-}$	During the learning activity, both teacher and learner select knowledge	↓
	F^{-}	During the learning activity, the learner selects knowledge.	Weak framing
Sequencing of knowledge	F^{+}	During the learning activity, the teacher sequences knowledge.	Strong framing
	$F^{+/-}$	During the learning activity, both teacher and learner sequence knowledge	↓
	F^{-}	During the learning activity, the learner sequences knowledge.	Weak framing
Pacing of knowledge	F^{+}	During the learning activity, the teacher paces knowledge.	Strong framing
	$F^{+/-}$	During the learning activity, both teacher and learner pace knowledge	↓
	F^{-}	During the learning activity, the learner paces knowledge.	Weak framing
Evaluation of knowledge	F^{+}	During the learning activity, the teacher evaluates knowledge.	Strong framing
	$F^{+/-}$	During the learning activity, both teacher and learner evaluate knowledge	↓
	F^{-}	During the learning activity, the learner evaluates knowledge.	Weak framing

The framing of the regulative discourse was analysed according to the following analytical framework.

Table 3: Framing of regulative discourse

F^+	During the learning activity, positional authority relations prevail.	Strong framing ↓ Weak framing
$F^{+/-}$	During the learning activity, both positional and personal authority relations prevail	
F^-	During the learning activity, personal authority relations prevail.	

The revised taxonomy (Anderson *et al.*) was employed to classify the level of knowledge taught and the level of cognitive process taught.

Collecting the data

Data were collected through consecutive lesson observations and video recording of four lessons per teacher. Lesson observations were arranged so that teachers would be observed teaching the *same topic* of the curriculum, i.e. naming compounds, writing formula, and balancing chemical equations. The video records were then transcribed. The transcripts of video-taped lessons were then divided into tasks. Only tasks where science knowledge formed the basis of the interaction were analysed. These tasks formed the 'unit of analysis' for this study. Forty-six tasks in 12 lessons were analysed. Table 5 shows the number of tasks that were coded for the four lessons that were analysed in each classroom.

Table 4: Number of tasks coded in each classroom

	School A	**School B**	**School C**	**Totals**
Number of lessons coded	4	4	4	12
Number of tasks	17	16	13	46

Analysis of data

For each task four kinds of analyses were done. Firstly, we identified how strongly or weakly the subject was classified. Secondly, we identified how strongly or weakly the teacher framed the instructional and regulative discourse. Thirdly, we classified the knowledge being taught into factual, conceptual, procedural and metacognitive knowledge, and fourthly, we classified the cognitive process expected of learners. What follows is an example of a task and the coding of the task according to the analytical criteria just described.

School A: Activity 14

Teacher: Right. Now we'll look at the first four. Right, pay attention. Right, who's prepared to give your answer for the first one? Number thirty? Chris? (*who had his hand raised*)

Learner: 1. . . 2. . . 1. . . 1. . .

Teacher: Right. Basically, we've got to put a two in front (*puts a two in front of NaOH to balance the equation on the chalkboard.*) Okay, you put a two in front of NaOH. Any comments about that one? All happy?

Teacher: Any questions about that one? Question. . .Yes?

Learner: I don't understand how you balanced number 31. *(referring to the equation on the c/b)*

$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

Teacher: Right, I've got. . . how many oxygens have I got here? *(pointing to $3NO_2$)*

Learner: Six

Teacher: *(points to H_2O)*

Learner: And that's five

Teacher: No, no, no, no. . .

Learner: It's seven, yah

Teacher: Six plus one is seven, yah. Here I've got *(pointing to $2HNO_3$)*

Learner: There's six

Teacher: Plus one *(pointing to NO)*

Learner: Gives seven

Teacher: Seven. Hydrogens? *(pointing to the H_2O)*

Learner: There's two

Teacher: Two there and. . . *(pointing to the $2HNO_3$)*

Learner: Two there

Teacher: Okay

Teacher: Right. Thirty-three? Lloyd?

Learner: 3. . . 1. . . 2. . . 1. . .

Teacher: 3. . . 1. . . 2. . . 1. . . (*writes the numbers in the appropriate places in the equation).* Okay; 3. . . 1. . . 2. . . 1. . ., any comments about that one? All happy? Right. Thirty-four?

Learner: Thirty-three

Teacher: Oh. Thirty-three. Sorry

Learner: 2. . . 3. . . 1. . . 3. . .

Teacher: 2. . . 3. . . 1. . . 3. . . *(as he says it out he writes the numbers in the appropriate places in the equation).* 2. . . 3. . . 1. . . 3. . . All happy with that? Okay, right.

Only science content is dealt with in this activity so it was coded as strongly classified or C^+. The teacher selected and sequenced knowledge – this was coded as F+. The teacher allowed learners to influence the pacing of knowledge, by allowing them to raise questions about the difficulties they experienced, and working with them through these difficulties this was coded as F-. The teacher provided explicit evaluation of learners' responses thus providing learners with opportunities to learn the legitimate text – this was coded as F+. Personalised authority relations prevailed – this enabled individual learners to ask questions and clarify their understanding – this was coded as F-. In the activity learners are expected to apply procedural knowledge. We have thus coded this activity as C/3 and recorded it as such on Table 6. (C meant that the activity dealt with knowledge at the procedural level, and three meant that learners and teacher in combination were involved in application of this knowledge to balance the equation.)

Results

The categories according to which each task was coded and analysed were collated and are presented in the table below.

Table 5: Results per school

Analytical criteria	School A (No. of tasks analysed =17)	School B (No. of tasks analysed =16)	School C (No. of tasks analysed =13)
Classification	C + (17)	C + (15)	C + (12)
Selection of knowledge	F + (17)	F + (16)	F + (13)
Sequencing of knowledge	F + (17)	F + (16)	F + (13)
Pacing of knowledge	F – (15)	F + (14)	F + (13)
Evaluation of knowledge	F + (17)	F + (16)	F – (12)
Regulative relations	F – (17)	F + (16)	F + (13)
Dominant knowledge	Factual (2), conceptual (3), procedural (12)	Factual (2), conceptual (7), procedural (7)	Factual (1), conceptual (2), procedural (10)
Dominant process	Remember (3), understand (11), apply (1), evaluate (2)	Remember (8), understand (4), apply (4)	Remember (10), apply (3)
Regulative relations	Personal (17)	Positional (16)	Positional (13)

Similarities across schools

All three teachers strongly classified science knowledge from other forms of knowledge. Of the seventeen tasks analysed in school A, 16 were strongly classified as references to everyday knowledge or other subject areas were minimal. In fifteen of the 16 tasks in school B, science knowledge was strongly classified. In one activity there was a sustained attempt by the teacher to show the relevance and use of the science knowledge in everyday life. Part of the discourse is presented below:

Teacher: Now nothing new. . . chemical reactions abound in our lives. Every time when you bake, it's a chemical reaction when you take the ingredients in their raw form transform it into something we call. . . and now it's in a more edible form. But you wouldn't go and empty a packet of baking powder into your mouth I need some cake flour later on and pour some vanilla essence into your mouth then shake your stomach (teacher shakes his body, class laughs) as you go on and see what happens. But you will need the ingredients, the cooking process will take place and something edible that tastes very nice and you eat lots of it. So those are examples of chemical reactions taking place. Chemical reactions abound, Every time you light a match, you got a chemical reaction going on there. Like now outside there the sun is shining and

> photosynthesis is taking place. Radiant energy is coming into plants' chemical reaction transforming uhh raw materials . . .(inaudible), now chemical reactions. In the science classroom now we later on focus very specific chemical reactions to start with.

In school C, science was once again strongly classified in 12 out of 13 tasks. There was just one activity where the teacher drew on knowledge related to mathematics to support science learning.

They also strongly framed what counted as valid knowledge and the sequence of concepts. In all three classrooms the distinctive concepts of physical science were being taught.

Differences across schools

(a) Pacing

At school A the pacing was weaker than in school B and C. Whole class, teacher led teacher-pupil interaction formed the largest proportion of classroom activity, followed by significant amounts of independent learner activity. The weaker pacing allowed learners to learn by discussion with their peers, by doing experiments, by observing results, explaining differences, asking questions, and constructing knowledge through interacting with the teacher and with their peers in their small groups. There was greater individual learner-teacher interaction on a one-to-one basis on the whole. This is illustrated by the excerpt below:

Teacher: And we said we gonna place those metals in solutions of their metal salts. So what were the solutions we had?

Learner: Iron chloride

Teacher: Iron Chloride (writes $FeCl_3$ on the table.)

Learner: Zinc Nitrate. . .

Learner: Magnesium Sulphate. . .

Teacher: Remember we changed. . .

Learner: Nitrate. . . and copper chloride

Teacher: Right, so what you started yesterday. You took. . . each of those metals and you placed them in different test tubes and then you chose one solution and you poured a little bit of that solution on top of each of those metals to see if there was a reaction. Now how did we discuss. . . what did we say how you will see if there is a chemical reaction or not?

Learner: The temperature.

The science inquiry process was simulated in the experiment done by learners in which learners were expected to discover the 'reaction on their own'. This is illustrated in the excerpt below:

Learner: It can vary.

Teacher: Yes, it does. It can be two or three.

Learner: So what if you say iron three chloride?

Teacher: Yes, what you trying to say?

Learner: Everybody keeps on saying iron chloride, sir.

Teacher: Oh, okay, it's preferable to say iron three chloride. You'll see of you look on the bottle it's labelled iron in brackets three chloride, okay?

Learner: Will it be the same reaction?

Teacher: You tell me. . .

The pacing was much stronger in schools B and C than in school A. In school B learners were required to check their conceptions with their peers with the teacher being in overall control. Learners did not check their understanding individually by asking questions or for clarifications.

The framing of knowledge was strong most of the time, but there were also opportunities for active learner participation. However, these were often limited to memorisation of formulas and to complete factual one-word answers to questions. Even though the teacher allowed learners some degree of participation, he remained firmly in control of the activity, and spent a substantial amount of time to ensure that organisational arrangements were firmly in place and clearly understood by the learners.

The even stronger pacing observed in school C resulted from the teacher transmitting information without opportunities for teacher-learner interaction or for learners to question, or to participate in activities so that they would be able to understand the meaning of the instructional messages.

(b) Evaluative judgment

The second difference is stronger evaluative judgment in schools A and B and weaker evaluative judgment in school C. In school A learners were given immediate feedback as the teacher responded to individual queries from learners, wrote solutions on the board or referred learners to the 'results they got in the textbook'.

Teacher: Okay. If there's a change. . . If we felt the temperature and it got increasingly hot, or maybe drastically quite cold, maybe that's an indication to us that there may be a chemical reaction.

Learner: There's a colour change.

Teacher: Maybe there's a colour change.

Learner: Bubbles rising. . .

Teacher: Maybe there's bubbles. There might be air bubbles indicating that a gas is being liberated.

Learner: Flames

Teacher: Flames? *(In a questioning tone eliciting laughter from class)*

Teacher: Okay, so what I asked you yesterday was to indicate with a cross if there was no reaction or with a tick if there is a reaction. Once you have done that, then turn to page 175 in your text books and then just compare your results to the results they got in the text book, okay?

Similarly in school B, the teacher provided evaluative judgment but of a different nature. The teacher devolved this role to learners themselves through the use of quizzes in pairs that was followed by the teacher calling out the correct answers. Teaching for examination purposes was illustrated with much of the teachers pedagogy aimed at memorising facts necessary for success in the high-stakes matric examination. In the teacher's words:

Teacher: The second one is the. . . your table of anions, your negative anions. You've done two tests already, and generally speaking, in a short time, you have internalised it. How well you've internalised it again is determined by how well you can report. That's the main thing. . . how well it's structured in your mind, okay. . . in your memory, will determine how well you can cough it out. So that at anytime we ask for a formula, you either refer to a table or reproduce it from what I call 'bloodstream knowledge'. It's there in your bloodstream, flowing. You want it; you take it out, okay?

In school C the lack of ongoing pedagogic judgment during the lesson did not enable learners to monitor their understanding as the lesson progressed. The following excerpt illustrates the long, explanations given by the teacher. In the activity the teacher is correcting a task that was set for the learners:

Teacher: Right let's try to mark this. Right, let's look at number one, this is actually called ammonium ion, note that it is coming from ammonia. That is ammonia and when it receives an ion negative, then it becomes ammonium ion with a plus, right? $NH_3 + H^+ \rightarrow NH4^+$. Not important but you need to know that. And what is the procedure here, how do we solve this, even if you can do two. How do we solve this if you are given the formula and you are required to write the names? I said you can use the Periodic Table; you can use the table of ions. Let's look at number one, if you can look at this formula, even though it is not that easy, you can see that this can be divided into that, into a positive and a negative ion, right? Because you need to identify those two, and you try to name the first ion, usually it tries to retain its name, its name is not completed, so this one (a) is ammonium, some are saying it is an oxide or whatever, but this is just a carbonate. By now you note that this two was actually coming from there. You see that? So if you check the ion here you must be sure of the chart. Which chart is that? It's not going to be a guess work, you need to know what you are actually looking for. Right next we had problem with this, assess the Co a small letter o there, meaning that this is a one element. And another thing, pay attention, The main element is copper, and I was trying to emphasize that why we telling that it is an element, it is the symbols, Capital letter and a small letter, one element not two. (b) Cobalt Chloride, what is the charge of the Cobalt? It's positive off course, but what is the magnitude?

Learner: Positive two.

Teacher: Positive two. How do you know? Actually what I am saying is these two actually goes there. You got that positive two there, and that will be Cobalt 2^{+}. We can't continue the period is over, but what you can do is try to complete this. This one you split it there and not there, how do we know where to split it, we don't have any rule. How do we know? I think we must have some guidelines, how do we know we are going to split it from the first not the second. Take a quick look at this ions, you note that the positive ions they are actually symbols, it is one so far that got positive and negative completed, ammonia, but the rest, in most cases they are metals, so all these metals are elements, they are the symbol elements, right? So you know that they are going to be broken here, and there is this ammonium. So far we (inaudible L makes a funny sound). Note that it is also not a metal. So it's a mystery in the true sense. And even hydrogen is not a metal, but the rest are metals. You just check them there, you know the names.

The weaker framing of evaluative criteria meant that learners were not provided with explicit evaluative judgment of their understanding through the lesson. The teacher would ask questions, provide the answer and then proceed to explain further.

(c) Dominant knowledge and process taught

In all three schools factual, conceptual and procedural knowledge was taught. What differed was the emphasis on teaching that facilitated understanding and the learning of specialised meanings. In school A much of the pedagogy aimed at facilitating understanding the meaning of the instructional messages and on acquiring the specialised meaning of what science is and how to do it; this was reduced in school B and non-existent in school C. In school B the emphasis was on remembering the technical terms with reduced attention to the cognitive processes of understand the meaning and apply. In school C the emphasis was on remembering the technical terms with complete lack of attention to learners understanding. The scaffolding was such that learners were taught to remember and recall factual and conceptual knowledge and apply procedural knowledge without understanding the meaning of the concepts taught.

(d) Regulative relations

The third difference observed was the regulative relations used by the teacher. In school A the pedagogic context was characterised by ease and friendliness. The personal regulative relations employed by the teacher enabled learners to feel comfortable about asking questions and checking their own cognitions. For a significant proportion of the teaching time, learners were able to participate actively in the construction of knowledge. This is illustrated by the excerpt below:

Learner:	Sir, so what happens if something like hydrogen is given off, but we've got no matches for the test?
Teacher:	Hold on. Don't worry about testing what specific gas is being given off, just see if there is a chemical reaction, okay?
Learner:	Sir, you know that the. . . iron chloride. . .
Teacher:	Yes?
Learner:	Chloride has got a valency of one?
Teacher:	Yes.
Learner:	So wouldn't it be iron two. . . uh. . . iron three chloride? Because isn't. . . doesn't iron have a valency of . . . of three?

In school B the social relations were positional and authoritarian. Both the instructional and regulative discourse was strongly framed by the teacher. The teacher strongly framed the selection, sequencing, pacing and evaluation of knowledge. During the learning activity, positional authority relations prevailed.

In school C the pedagogic context was also characterised by authoritarian positional relations between learners and the teacher. Then the strong framing of regulative relations further negated possibilities of learners questioning or making their understanding known.

Interpretation/discussion

The first inference is that the 'discursive rules of pedagogy' are strongly influenced by the 'structural conditions' of each school. In other words the pedagogic discourse and relations observed and described above occur within specific structural conditions within specific school contexts. In this section the concepts of fortified and exposed school contexts are used to reinterpret the patterns identified. The key analytical criteria are tabulated in Table 6 below:

Table 6: Structural and discursive practice per school

Analytical criteria	**School A (N of tasks analysed =17)**	**School B (N of tasks analysed =16)**	**School C (N of tasks analysed =13)**
Class size	28	38	24
Resources	Ample	Adequate	Lacking
Teacher qualification	Sec teacher's diploma	BSc, HDE	BSc, MEd
Classification	C + (17)	C + (15)	C + (12)
Selection of knowledge	F + (17)	F + (16)	F + (13)
Sequencing of knowledge	F + (17)	F + (16)	F + (13)
Pacing of knowledge	F – (15)	F + (14)	F + (13)
Evaluation of knowledge	F + (17)	F + (16)	F – (12)
Regulative relations	F – (17)	F + (16)	F + (13)
Dominant knowledge	Factual (2), conceptual (3), procedural (12)	Factual (2), conceptual (7), procedural (7)	Factual (1), conceptual (2), procedural (10)
Dominant process	Remember (3), understand (11), apply (1), evaluate (2)	Remember (8), understand (4), apply (4)	Remember (10), apply (3)
Regulative relations	Personal (17)	Positional (16)	Positional (13)

School A: A fortified school enabling inclusion in specialised science discourse

The advantaged material conditions in the school included a wealth of material resources to support good teaching including a well-stocked laboratory and teaching aids such as an overhead projector, a television and video projector. Each learner had their own science textbooks and study aids. The majority of the children came from higher socio-economic status homes; the physical science teacher had the necessary qualifications to teach science. The smaller class size was another advantage. Then, to facilitate the teaching a laboratory assistant was on hand to assist during practical lessons.

Within this advantaged material context pedagogy for optimal learning of science knowledge and process was observed characterised by intellectual rigour and supportive and personalised social relations. The discursive practices characterised by strong classification of science; the strong framing of selection, sequencing and evaluative criteria provided learners with opportunities to learn the specialised epistemology of science, its epistemic processes, its technical language, its concepts in meaningful ways. The weaker and differentiated pacing and personalised regulative relations contributed to a supportive classroom where learners felt sufficiently empowered to ask the teacher questions whenever they did not understand something. These findings are consistent with Wallace, Tsoi, Calkin, Darley (2003) who hold that teaching for understanding science include the strategies of ‘a supportive environment, questioning in the discipline, opportunities for talk and negotiation of meaning and interactive problem-solving. Rigorous teacher questioning of learners, individual and group activities, allowed for progression beyond the *remember factual knowledge* level to understand science knowledge. These findings are consistent with Schroeder, Scott, Tolson, Huang and Lee (2007) that alternative teaching strategies such as questioning, manipulation, enhanced materials, enhanced context and collaborative learning enable effective teaching. Opportunities to enable understanding related to the nature of the activity. In fact, it appeared that opportunities to work with/engage in the higher levels of cognitive process were dependant on the pedagogical choices made by the teacher. The learning activities allowed for a greater degree of learner engagement in higher level processes. A change in the teacher’s role from instructor to facilitator that allowed students to look to each other for support (Krystyniak and Heikkinen, 2007); and helping students to seek evidence and reasons for knowledge claims may “help shift their view of science away from science as a static set of facts to science as a social process where knowledge is constructed" (McNeil and Krajcik, 2008, p.54).

In school A, weaker pacing in tune with learners acquisition of the concept ensured that there was synergy between the teachers aim and the learners progress in acquiring the concept. The combination of learners from middle SES backgrounds, better resources, small class size, and pedagogy characterised by: strong classification of science; the strong framing of selection, sequencing and evaluative criteria; weak framing of pacing and regulative relations; the higher knowledge levels introduced and higher cognitive processes expected provided learners with more optimal opportunities to learn and understand specialised science.

Learners were provided with learning opportunities to achieve progression in the quantity and depth of understanding of key concepts, together with an increasing understanding of the connections between different concepts in order to develop a well-organised knowledge base. As such they were given learning opportunities for achieving the official curriculum outcomes (Learning Outcome 1 and Learning Outcome 2) to a greater extent. In addition to factual and procedural knowledge learners were expected to know and understand conceptual knowledge as well. In addition to remembering and understanding knowledge, learners were given opportunities to apply science in experiments and discuss conjectures about the outcomes. This included claims, argumentation and evaluation. Thus, learners were given access to specialised science knowledge and processes of inquiry in science.

School B : A less fortified school enabling inclusion in technical science

This school exemplified characteristics of both 'fortified' and 'exposed' schools' but had more in common with fortified schools. The physical science teacher had completed a BSc degree with chemistry and physics as major subjects. The classroom was a science laboratory supplied with water, gas and electricity. It was resourced with an overhead projector and had laboratory equipment to support practical work. The walls had a variety of science related posters on them, with a large periodic table featuring predominantly on one side of the classroom. A set of textbooks was provided for learners to use during the lesson and give back for use by other classes. Clearly evident, in the classroom was a set of reference books for the teacher's personal use. The school differed from fortified schools in two ways. The children come from lower socio-economic backgrounds and it had a much larger class size. The first experience on walking into the classroom was one of being overwhelmed by a large number of individuals seated close to each other. The last row of students was more than ten metres away from the teacher when he was at the chalkboard.

The larger class size altered the nature of instructional and regulative discourses significantly. The teacher did not relax his control over both the instructional and regulative discourse. Firstly, with reference to the instructional, there was stronger and undifferentiated pacing. All learners were expected to learn at the same pace set by the teacher and check their responses with what the teacher called out for all. Learners did not check their understanding individually by asking questions or asking for clarifications as in the previous classroom as the lessons progressed.

Secondly, the larger class size made greater pedagogic demands on the teacher. The excerpt below is used to illustrate the greater demands made on the teacher in comparison to the previous teacher in the fortified school:

Teacher: Okay, Right. Let's start. A. . . *(points to learner in front)* A. . . say it. . . *(then points to the next learner and gets her to say B and so on until E).* Wait, you remembering what you said. Today I'm calling all As, all Bs, all Cs as yesterday, okay? Sorry, we've gone A, B, C, D, E *(points to learners in the front row who have already called out letters, then on to the next row).* Let's go. . . *(learners call out up to H, and then he gets them to start again from A up till H, repeats this pattern until all the learners have been assigned a letter except for one learner remaining)* Okay, looks like I'll be testing you. I'll be taking you separately. Right, very **quickly**, all As hands up please. 1, 2, . . .4, 5. Right, As step out please this side. Bs on this side. Take one each please, **quickly** *(hands groups a set of cards, one for each person).* As this way to my right. Bs this way. . .take one each. Cs? Those who have their hands raised. Give them one please *(hands to learner in front to give cards to group C members).* Ds? *(another learner takes and hands out to the D group members – continues like this until all the groups have a set of cards)* Right, these are for your eyes only, okay. Not to show others. Okay, do not reveal, especially to the person whom you might be testing? Everybody has a test? Check please. Everybody has a test now? *(sorts out some learners who did not have)*. As and Bs. . . Okay, let's go Cs and Ds? Cs there. . . Ds there *(points to places in the class where they should group*). I want four Cs, four Ds. **Don't sleep.** Cs and Ds. Please work with a pen or a pencil in your hand, it makes it easier. **Let's go quickly**. Where's number 4? Four, is that you? **Quick** my girl, come on. E and F *(points to other spots in the classroom).* E. . . F. . . let's go people. *(claps his hands)* Right, the rest of you, just hold it okay. Very **quickly**, where's your Gs

> *(puts a G together with an H)* You will test. Who doesn't have a partner? There should be one. We had an odd number. Right I will test you. Right, let's go, one A and one B. As you are standing. . . next two. . . You can sit or stand anywhere, okay. Just don't reveal the answer to your friends. Right, make sure it's A and B. Not the same. Let's go Cs and Ds. Just find two stools and sit down. Es and Fs. . . as you stand. Right, the test commences now…

- greater advanced planning was required by the teacher to prepare the speed tests on cards so that some measure of success was achieved in the classroom.

- more time was used during the lesson to arrange the activity and then to execute it.

- the teacher distinctly showed signs of distress relating to being able to manage the learners and the activity and time successfully – in the above excerpt, the teacher used the word 'quickly' four times and quick once and even went so far as to tell learners 'don't sleep'.

Thirdly, the larger class size impacted on the nature of the evaluative judgment given – in school A learners were given immediate feedback as the teacher responded to learners, whereas in school B there was less frequent evaluative feedback and the teacher devolved this role to learners themselves through the use of quizzes in pairs that was followed by the teacher calling out the correct answers for all. Fourthly, the positional authority relations observed were also due to the larger class size. Keeping greater distance from the learners discouraged individualised and personal social relations from developing.

The discursive practice observed enabled restricted access to the specialised epistemology of science. The emphasis was not on understanding and acquiring its unique epistemic processes but on remembering factual and conceptual knowledge for examination purposes and on applying procedural knowledge in the examination. While these students would probably do well in the examination the opportunities for understanding science was limited or non-existent. Lessons were strongly controlled by the teacher, and there were reduced opportunities for dialogical interaction and independent learner activity. The discursive practices required that learners *'remember conceptual knowledge',* and '*apply procedural knowledge'*.

At school B the main factor impacting negatively on pedagogy was the larger class size. The range of factors that would enable productive pedagogy; a highly qualified and professionally disposed teacher; adequate resources, strong classification of science and the strong framing of selection, sequencing, evaluative criteria; were undercut by the larger class size with concomitant strong and undifferentiated pacing, and distant and authoritarian regulative relations between the teacher and learners from lower SES backgrounds.

School C : An exposed site excluding learners from science

This school also had characteristics common to both fortified and exposed school types. Characteristic of exposed schools, the children come from severely impoverished socio-economic backgrounds and the resources and facilities available for teaching and learning were either non-existent or in a state of disrepair. Characteristic of fortified schools, the physical science teacher is well qualified to teach the subject and the much smaller class size is characteristic of fortified schools. But, discursive practices observed were far from enabling access to the epistemology of science. The stronger, undifferentiated pacing and the positional and authoritarian regulative relations denied learners opportunities to ask questions and to clarify their conceptions. Lessons were dominated by a large amount of content-based teacher talk, with little learner participation and learner activity. Then the lack of ongoing evaluative feedback during the lesson did not enable learners to check the validity of their cognition. Teacher-talk characterised most of the activities, with little opportunity for interaction and learner activity. The pedagogy illustrated what McNeil and Krajcik (2008, p.54) refer to “science as a static set of facts rather than science as a social process where knowledge is constructed”.

While the teacher had moved to teaching strongly classified science the emphasis was on remember factual knowledge. It is unlikely that students would master sophisticated forms of knowing and thinking scientifically. As such learning opportunities to achieve Learning Outcome 1 (the development of practical scientific enquiry and problem-solving skills) and Learning Outcome 2 (that learners are able to construct and apply scientific knowledge) were not made available to learners. Conceptual progression, deep understanding of concepts as well as the connection between concepts to develop a well-organised knowledge base was not enabled. Similarly, the teacher emphasised low level cognitive processes of recall and recognition of science knowledge and paid little attention to higher level cognitive processes. There was an emphasis on *'remembering procedural knowledge'*. Pedagogical choices resulted in learners working at low levels of knowledge and process. These findings confirm Fleisch (2002, p.118) who noted that in historically disadvantaged schools ". . .teaching . . . seldom translated into the mastery of sophisticated forms of knowing and thinking or school knowledge".

At school C the combination of learners from poor backgrounds, lack of resources, strong classification of science and the strong framing of selection, sequencing, pacing and regulative relations; weak framing of evaluative criteria and the lower knowledge levels taught and lower cognitive processes expected provided learners with restricted opportunities to understand science.

The stronger pacing in spite of the smaller class size could be explained by the dominant practices within the school. Education, knowledge and time were not highly valued in the school. The school allowed learners to go home during the lunch break. Many did not return for the lessons in the afternoon. A range of other activities disrupted teaching regularly: choir practice, cleaning the school floors, picking up litter, participating in sporting activities with other schools in the area, raids to recover school property from the surrounding homes. It must be added that due to lack of funds for cleaning the school it had no option but to get students to clean the classrooms themselves. That this happened every Friday from 1 to 2.30 meant that instruction time was depleted. During instruction time many students would be wandering around outside. Many teachers would not be in their classrooms. Much school property such as chairs, tables, desks were stolen and it had become common practice for the school staff and students to carry out regular 'raids' and searches of homes surrounding the school to recover school property. This happened on one of the days of data collection. Although the science teacher is highly regarded as one of two teachers in the school who is committed to his profession, the expectations of students formed by the dominant practices in the school prevented them from engaging actively with physical science.

Conclusion

We set out to investigate the impact of school type on opportunities to learn science in diverse school contexts. Consistent with Bernstein's premise the findings show that the structural conditions of a school and the discursive rules of pedagogy generate practices of inclusion and exclusion. Specifically, it shows that class size and resource provision and the dominant pedagogic practices in a school are key elements impacting on pedagogy in the classroom.

The discursive practices of teachers are subject to a range of objective conditions prevailing in the school. It was clear that learners had unequal opportunities to learn the same ‘topic’ in the three classrooms. These variations emanated from: objective conditions such as class size, availability of resources and the social class context of the school; and discursive practices such as pacing and evaluation of learners’ on-going understanding within enabling or disabling authority relations in the classroom. In all three schools there was strong classification of science, and strong framing of selection and sequencing. The differences in pacing, evaluative judgement, time taken to arrange activities and regulative relations account for differences in opportunities to understand and learn specialised science.

These case studies of pedagogy analysed are consistent with other South African writers such as Hoadley (2007), Reeves and Muller (2005), Harley and Wedekind (2005) and Reddy (2005) that learning opportunities differ significantly in South African classrooms. The opportunities to learn at the upper working class school seems to support Reddy’s (2005) assertion that access to higher levels of knowledge and process is dependent on the social class of learners. The students from the different race groups at the middle class school had one thing in common – they were able to afford the higher school fees charged and thus able to access the ‘improved learning opportunities, improved performance and improved life prospects’. Well-to-do Black students have accessed the better learning opportunities at the ex-White model C school. At the previously disadvantaged ex-HOD school the larger class size reduced opportunities for learner directed pedagogy. Hoadley (2003) pointed out that teacher-learner interaction in the working class school that she studied with 57 learners was three times less than schools with 30 learners. An intervention in school B that would immediately create more conducive conditions for more productive pedagogy would be to provide the school with a lab assistant to assist the teacher.

The deep-seated inequalities in access to knowledge that appear to have been institutionalised in the classrooms imply different values, power and life chances for learners. Black learners at the exposed school did not equally enjoy their democratic pedagogic rights to intellectual enhancement, inclusion and participation (Bernstein, 1996) in socially valued levels of science knowledge and processes. More than forty years ago, writing about science education under Bantu Education, Horrel (1968, p.72), noted that children "gain little or no conception of basic principles" and "as few practical experiments are undertaken . . .the pupils fail to develop the ability to reason, to solve problems, and to draw correct conclusions from their own observations". This holds true today in this school. At this school more teachers who are qualified to teach the subject they are teaching and who have a professional disposition are necessary to contribute to the formation of an ethos conducive to robust teaching and learning.

With reference to curriculum policy goals of equity in quality of learning experiences, actual opportunities to learn science at both extremes of the socio-economic spectrum are reminiscent of apartheid structured inequalities. For the school in the middle, a site of much change in learner enrolment, the larger class size has produced its own set of challenges for the teacher with concomitant effects on frequency and type of evaluative feedback, on pacing of knowledge, on the amount of time used to arrange and complete activities, and on the quality of regulative relations in the pedagogic context resulting in significantly reduced opportunities to understand science and to learn its specialised meaning. In the three cases researched here, opportunities to learn appear to be strongly conditioned by the type of the school. This points to the determining effect of school type on learners' experience of the physical science curriculum. Based on these case studies of science pedagogy, we conclude that because opportunities to learn science are stratified, student performance in science will continue to reflect race and class stratification.

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