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A Case for Critical Constructivism and Critical Thinking in Science Education

Mike Watts
Roehampton Institute

Zelia Jofili and Risonilta Bezerra
Universidade Federal Rural de Pernambuco

Abstract

While constructivism has made a considerable mark concerning learning in many areas of school learning, much less is evident relating to the education and professional development of teachers. This paper not only deals with the implementation and evaluation of such a constructivist course, but extends the argument towards the induction of teachers into "critical constructivism" through their own action research projects. Data is drawn from a single case study which illuminates the induction process and illustrates the changes taking place in the professional life and the reflective practice of one teacher as she deals with scientific concepts with two classes of 11-15 and 18-25 year olds. The Brazilian setting for the course lends resonance to its international significance.

Hawkins (1994) traces constructivism back to Socratic and Platonic practices and, more recently, to respectable origins and pedigree in the eighteenth century philosophies of Kant and Giambattista Vico; the nineteenth century writings of Froebel in Europe; and, the early twentieth century educational philosophy of Dewey in the USA. Beyond this, there have grown many brands and degrees of constructivism which include personal constructivism (Kelly, 1955), social constructivism (Knorr-Cetina, 1981), radical contructivism (von Glaserfeld, 1984), critical constructivism (Kincheloe, 1993), along with weak, strong and pragmatic versions (Watts & Bentley, 1991).

As a broad principle, constructivism presupposes that knowledge is actively constructed by learners through interaction with physical phenomena and interpersonal exchanges. As concisely distilled by Arib and Hesse (1986, p. 176), people construct conceptual frameworks of the natural and social world in a complex feedback process, in which theoretical models and sensory input are assimilated and accommodated in a self-modifying sequence of prediction and test. This is a perspective which views knowledge as organised into, and by, conceptual frameworks–explanatory frameworks which are constructed and, in turn, serve to act as interpretative lenses for the understanding of phenomena and experiences (Watzlawick, 1984). While constructivism is commonly denounced as solipsistic and anti-realist (Mathews, 1994) there is within its writings, however, no denial that reality exists–simply that it can only be known through construction and interpretation. As Ogborn (1995) says:

> ... we do not know anything for certain; what we do have is fallible, partial, corrigible knowledge of how things are in the real world, together with an apparatus of formal constructs which enables us to imagine how things might be. (p. 12)

The setting for the work reported here lies in science education in schools in the UK and Brazil, and focuses on teachers' thinking, not in terms of content, but on their approaches to constructivist teaching and learning (Jofili & Watts, 1995; Vaz & Watts, 1996). The vast bulk of

work within constructivist science education within the international arena, has dealt with pupils thinking, and this has been a major paradigm of enquiry over the last two decades. Work on prior learning in science has now been extensively catalogued, for example, by Carmichael, Driver, Holding, Phillips, Twigger and Watts (1990), Driver, Guesne and Tiberghien (1985), Fensham, Gunstone and White (1994), Gilbert and Watts (1983), and Pfundt and Duit (1994).

Constructivist research into teachers' thinking is relatively new (Bell & Gilbert, 1996; Day, Calderhead, & Denicolo, 1993), and Hand and Treagust (1994) note a general paucity of constructivist research in teacher education. The ways in which teachers develop their classroom practice is intrinsically tied to their understanding of how pupils learn, and to their own lived experiences of schools and schooling–even though this may not always be clearly articulated. Studies of teacher thinking, as Clark and Petersen (1986) suggest, hope to "understand and explain how and why observable activities of teachers' professional lives take on the forms and functions that they do" (p. 255). Indeed, we see our studies as moving beyond constructivism as such and to adopt a critical constructivist stance in order to explore both the sense of teachers' interpretations of learning and the settings within which these are created. We return to these ideas later in the paper.

Constructivist Teaching

Along with the term constructivist learning, the term "constructivist teaching" has also increasingly crept into use. This has generated some controversy (Fensham *et al.*, 1994; Mathews, 1994) with the common denial that it is possible for teachers to "construct" knowledge for a learner, or for learners to have conceptual change constructed for them. Similarly, many see the notion of constructivist teaching to be oxymoronic, "to teach" becomes synonymous with "to instruct," and the terms construction and instruction together are paradoxical.

The dichotomy for most classroom teachers, of course, is that they have a responsibility to enact agendas from outside the classroom societal imperatives and the intended curriculum are dominant within educational systems world-wide. There are times when teachers must perforce be didactic and say what pupils *should* do in order to achieve certain aims. The agenda is clear, the *teacher* knows the way to do it. For constructivist teachers however, it is a matter of balance and their range of teaching strategies and techniques must vary across a wide spectrum, from overt classroom control to covert conceptual change and back again. While there must be room for input, exposition, explanation, demonstration, description, direction, reference, showing, modelling and so on , the overall balance must be towards teaching-as-managing, not teaching-as-telling.

In different parts of the world, some structure has been developed for both constructivist teaching (e.g., Northfield & Symington, 1991) and a "constructivist curriculum" (Bell, 1991). In her teachers' guide, for example, Bell (1993) describes four forms of constructivist relationship between teacher and student–power-on, power-off, power-for and power-with. The first is traditional teaching (instruction): while aware of pupils' prior knowledge, the teacher's own agenda is paramount and students are directed to the learning to be done. Power-off, too, is traditional in that it is the reverse of power-on, the teacher ignores constructivist learning opportunities and maintains his or her own frameworks for classroom interaction regardless. In power-for and power-with, Bell shapes the acceptable faces of enabling teaching, where the teacher works alongside the student either guiding and structuring or (better) democratically learning together with the student. Bell's guide provides a range of strategies for teachers to achieve these latter forms and to change their general approaches to teaching and learning. She suggests that, too often, facilitators act as experts with good advice to give, thus "reinforcing the expert-novice dichotomy" (p. 9); empowerment, in contrast, must act to diminish expert-novice dependencies.

In more prosaic practice, constructivist teaching is seen to be more effective where lesson planning is inclusive of the ways in which pupils learn, the nature of conceptual change, the prior concepts that they hold and the routes which lead from childrens' science to scientists' science. In practice, being aware of pupils' prior concepts enables teachers to plan strategies for reconstruction towards school science orthodoxy. In the science classroom, the teacher can encourage pupils to test their own ideas, compare these with accepted scientific knowledge and look for some movement in their thinking from the one to the other. Fostering conceptual movement is important in order to encourage qualitative leaps in pupils' thinking–the intention being that new knowledge is not learnt mechanically but is actively built up by the pupil.

In the UK, Driver and Oldham (1986) have suggested a constructivist teaching scheme in five phases: orientation (focusing children's interest on a particular scientific issue); elicitation (helping children become aware of their prior knowledge and helping teachers gain access to the range of children's ideas); restructuring ideas (helping children become aware of an alternative point of view, critically examine these, and to test, modify, extend or replace their prior concepts); application of new ideas (reinforcing the newly-constructed ideas); and, review (reflection on how much their ideas have changed). This approach has a particularly cognitive flavour, has been developed through a number of studies. The opportunity to develop a full and searching evaluation, though, is still some way off.

Critical Constructivism

In our own research we take the broad view that the kinds of conceptual change which are of greatest interest are not those which concern simple linear situations with direct exchange between old and new conceptions. Instead, we are concerned with complex multi-layered circumstances which entail, for instance, awkward or unresolvable issues which cannot be tackled easily issues which are commonly combined within tangled and difficult situations. An example is illustrated through our case study where the teacher (named Riso) is working within a demanding professional situation, inside a broadly unrewarding institutional and financial setting. From this point of view, the need to re-structure or re-construct thinking develops from personal or subjective states, requiring some change in the actors' circumstances or situation for resolution to happen. This is a fairly general description and, of course, there are many different and specific contexts in which re-thinking or re-conceptualisation can be fostered and generated. Our suggestion here is that processes of conceptual change are not necessarily identical or isomorphic across domains, but that thinking is context based and situation specific (Rogoff & Lave, 1986). It is for this reason that changing thinking in professional matters demands huge flexibility and critical thinking from teachers. Needless to say, not all issues and problems in all situations can be resolved–some have cost, personal risk, or social and political implications that require complex initiatives at different levels to reach outcomes.

This view of constructivism and conceptual change is at variance with usual descriptions. The vast bulk of research in science education deals with teachers' and learners' approaches to well-structured knowledge domains, and constructivist teaching is commonly used to shape and channel such learners' understanding and then, later, to test for achievement through application (Driver, Squires, Rushworth, & Wood-Robinson, 1995).

The handling of more complex forms of conceptual change is, in contrast, under-researched (Roth, 1995). There is precious little literature available in cases where situations (for example, particular teaching situations) are not easily structured, or where learners have few definitive paths for development. This scarcity of research is compounded when conceptual change and re-construction additionally include issues of attitude, affect, emotion and the disposition of the

learner. In such cases, re-construction of thinking includes not only rational, algorithmic and heuristic routines, but also involves doubt, tangible costs and benefits, confidence, interest and motivation as well as "hot" emotions such as anxiety, frustration, fear and joy. In these circumstances, situations involving conceptual change are part of the messy and ill-defined business of real every-day life (Alsop & Watts, in press).

Our supposition here is that, in order to conduct such processes within education, teachers must possess critical awareness. Critical awareness implies an understanding of themselves, their perspectives, their approaches to the construction of knowledge, and ways in which their own consciousness has been shaped by society (and schools). They must understand the roles played by schools both in developing or in repressing this awareness; its roles in socialising thinking. A further concern within this approach to constructive critical thinking is that pupils themselves, too, need to appreciate the nature of the innovation being practised on them (Baird & White, 1993). That is, teachers need also to foster critical-awareness in pupils–a task which is, however, very difficult to do.

In order to establish some shape to the discussions and data to follow, we need to explore the notion of critical constructivism further. First, it can be seen to be concerned with "first degree" constructs which entail knowledge in the world first-hand experience, "hands-on," on-the-scene understanding of phenomena (Lowe, 1982). This contrasts with "second degree" constructs which involve social scientists' interpretations of first-degree constructs– "outsider" interpretations of "insider" experience and knowledge. Kincheloe (1993) describes critical constructivism as follows

> Critical constructivists [...] ask what are the forces which construct the consciousness, the ways of seeing of the actors who live in it. [...] Critical constructivism concerns the attempt to *move beyond* the formal style of thinking which emerges from empiricism and rationalism, a form of cognition that solves problems framed by the dominant paradigm, the conventional way of seeing. (p. 110, emphasis added).

Critical Action Research

We have adopted critical action research, which we have based on the assumption that the methods and issues of research are always political, so that teacher education must be both socially and politically contextualised. Critical constructivism leads to a form of professional problem solving (Watts & Vaz, in preparation), entailing the devolution of responsibility for learning to the learner. This, in turn, leads to the use of action research and action learning (Pedler, 1983) during in-service teacher education, formative in helping teachers shape their thinking about classroom practices. Action research can provide teachers with the opportunity to test hypotheses and, consequently, to search for improvement in their own teaching. Critical constructivism provides teachers with the opportunity to contextualise that thinking within a broader social, historical and political context.

Contextualisation in this form plays a vital role in researching teachers' practice within their subject matter teaching. For example, although investigators can decide to involve teachers in some aspects of their planning, execution and interpretation of research into school practice, the historical roots of the problem might well be ignored. In short, critical constructivism enacted through teachers' action research is seen to be an attempt to tackle human purposes, paying attention to human dignity, freedom, authority, and social responsibility. Kincheloe (1991) says

> Never content with what they have constructed, never certain of the system's appropriateness, always concerned with the expansion of self-awareness and consciousness, the critical action

researcher engages in a running meta-dialogue, a constant conversation with self, a perpetual reconceptualisation of his or her system of meaning. (p. 114)

A Brazilian Context

Brazil is a country full of contrast. At both and the same time it displays characteristics of developed and undeveloped countries. According to educational legislation, compulsory and free education in Brazil happens for the age 7 to 14 years old, as shown in Table 1.

Table 1
School Levels, Ages and Types of Schools in Brazil

School levels in Brazil	Ages	School
Compulsory entry to state school	7	-
Pre-school	3-6	private
Primary school	7-10	state/private
Secondary school	11-14	state/private
Vocational/Academic preparation	15-17	state/private
Entry to University	18	state/private

However, Brazilian educational law is fairer in policy than it is in practice. Pre-schools (the majority of them) are fee-paying, so people who have no means to pay cannot send their children to school. As a result, at age seven and the point of entry to state school, they often fail to be "schooled" because they have never been in formal education before. Only 17% of children starting in Year 1 (seven years old) reach Year 8 (14 years old). There are many reasons for this high rate of failure and drop out: children's economic poverty; the teaching profession has low social status due to teachers' very low salary levels; teachers work in two or three different schools each week in order increase their income; teacher education has long proved ineffective and very little has been done to improve this; it is difficult to dismiss bad teachers in state schools; poor working conditions at state schools, such as lack of basic equipment and other facilities; students' diverse backgrounds make lessons very difficult for teachers who must manage large classes–commonly 45-60 children per class; a text-book emphasis on factual information, an emphasis on exercises–stressing memorisation skills rather than conceptualisation; few hours in the school day, 2.5 to 4 hours for most pupils.

In view of all this, it seems hard to believe that any academic progress is possible at all. Reversing this situation will only be possible through the adoption of strong social structural changes to make possible redefinition of priorities concerning allocation of resources to education. This, though, is clearly a long term political operation. While this position matures it is necessary to start from present circumstances and look for new teaching alternatives so as to allow a greater number of children to benefit from formal education.

Teachers at primary school level commonly train at vocational school for a minimum of 3 years. There is also a four-year course at university level for the preparation of primary teachers,

but that is a desirable not a formal requirement to teach primary children. Teachers of science at secondary schools have to hold (as a minimum) a certificate of a three-year science course at university. Teachers for vocational or academic courses for preparation for university entrance need to follow a four-year concurrent science course leading to a certificate to teach the separate science disciplines (biology, chemistry, or physics).

As elsewhere (Kincheloe, 1993), teacher preparation in Brazil appears to be in a state of crisis. Teachers feel lacking in both content knowledge and pedagogical knowledge. They experience problems related to the balance between theory and practice and between content knowledge and pedagogical knowledge. Moreover, impoverishment and the consequent lack of resources create problems that are particular to countries in development. These are political, social and economical issues that must be faced.

The teachers within our study all attended a two-week inservice teaching course (INSET)(Jofili & Watts, 1995) predicated on a design similar to that of Bastos (1992). During seminar and tutorial time the participants were required to articulate their thinking towards individual action research projects to be undertaken in the following weeks in their own classrooms. Their commitment was to develop and test teaching units which use constructivist principles, and which were to be evaluated through action research projects in their own schools. It was also part of the programme that, as these teachers undertook innovation within their own classes, they would become aware of real dilemmas concerned with the normal expectations and practices within their school–so requiring them to confront social, political and historical issues in the practice of education in the context of their community. At the end of one month the participants were asked to report their work and progress at a feedback seminar.

In adopting a critical constructivist approach, we rejected the notion of a-critical, a-historical and out-of-context action research in the shaping of teachers' thinking on their own practice. Too often, action research has focussed too narrowly on immediate problems without broadening to describe a wider context and situation. Too often, too, the methodologies involved have been left unexplored to an appropriate depth. The focus of the action research projects in this work, was not just the personal and professional growth of the teachers themselves but also a raising of consciousness of their circumstances and conditions, as well as–as noted earlier–the development of critical thinking of the students involved. This embodied the principle that the best way to encourage teachers to re-think their practice is for them to study particular students, observing the particular contexts from which they emerge and the particular ways they undertake the search for meaning. As Kincheloe (1993) says:

> In this process critical constructivist teachers set up conditions that encourage student self awareness and reflection, hoping to facilitate further growth through individual awareness of the nature of prior growth. (p. 125)

An Approach to Critical Thinking

Our primary interest in this study has been to observe features within teacher thinking and practice which relate particularly to critical constructivism and critical thinking. To this end we have developed a general description of critical thinking, which we suggest is a process of internally examining and exploring issues of concern, triggered by certain experiences, which create and clarify meanings in terms of self and others, and which results in changed conceptual perspectives and relationships. We have seen our role as fostering critical thinking and encouraging the externalisation of this process as and when it is appropriate. This in turn has led us to an inclusive four-step model (Jofili, 1997) of teacher movement towards eliciting critical thinking, as shown in Figure 1.

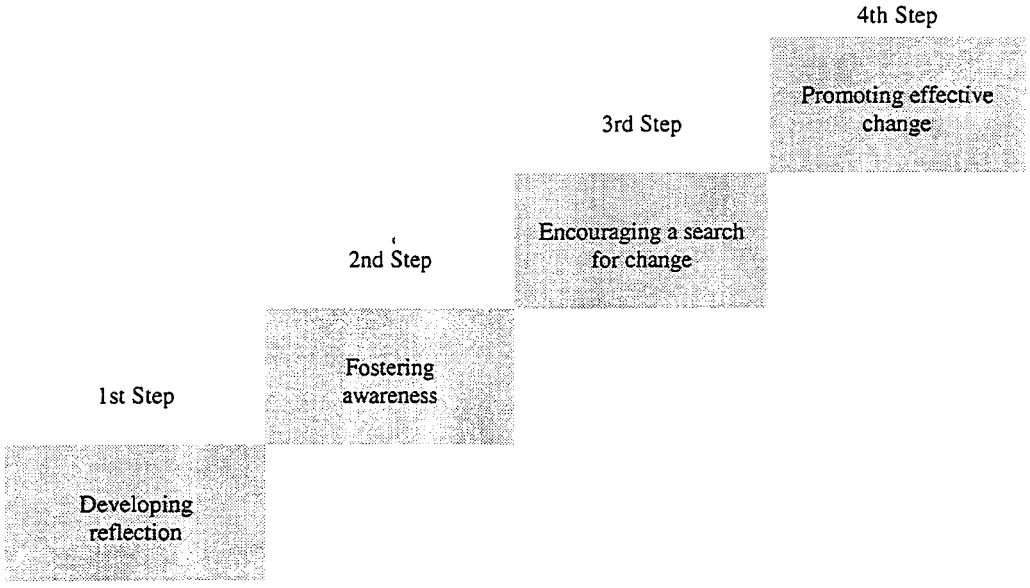

Figure 1. Four steps to critical thinking.

From this model, the first step towards developing critical thinking is the identification of particular kinds of reflective practice from within teachers' discourse and deeds. As a consequence of discussions and reflection, we suggest (Step 1) that teachers generate awareness and become more clear and insightful of their classroom practice and school context. Awareness is described through three sub-categories awareness of his or her learning from reflection, awareness of self-constraints (critical appraisal of his/her potential) and awareness of external constraints. As result of both reflection and increased awareness, we suggest the second step is Seeking Change. At such a point, teachers might ask "What needs to be done next? How can I do it?" This category is also divided into different kinds of changes in personal thinking (increasing their awareness); changes in students' critical thinking (their empowerment and citizenship), and changes in teachers' perceptions of students (as subjects rather than objects of learning).

A third step concerns "Effecting Change" which is related to the same sub-categories as described in Step 3. These steps are shown in Figure 2.

In this sense, critical thinking is a lived activity, not an abstracted academic pastime. Teaching is a complex enterprise, and it commonly requires time, energy and support in order to step outside its perplexities–we have seen our support in terms of facilitating the generation, fostering and promotion of critical thinking with the teachers within our purvue.

a) Developing reflection	1) internal examination of self
	2) experimenting with thinking
b) Fostering awareness	1) external constraints
	2) self-constraints (self-criticism)
	3) self-learning
c) Encouraging a search for changes	1) in students' critical thinking
	2) in students' or teacher's self empowerment
	3) through changing reality
	4) in students' or teacher's own citizenship (cooperation)
	5) in understanding students as subjects in the learning process
d) Promoting effective change (in thinking, in practice, etc.)	1) in students' critical thinking
	2) in students' or teachers' self empowerment
	3) through changing reality
	4) in students' or teacher's own citizenship (cooperation)
	5) in understanding students as "subjects" in the learning process
	6) through own critical thinking
	7) through self-learning

Figure 2. Steps towards encouraging change.

Perceptions From a Case Study

Riso is 30 years old and has been teaching science for nine years. She holds an undergraduate certificate in science and biology and a qualification in education. She is currently teaching science at a state school (Year 7 to Year 9) for children (aged ten to sixteen years) and for young adults (aged 18 to 25 years). Over the period of our study she was teaching 60 hours a week in two schools and in 13 different classes.

Riso decided to take part in our INSET course (Jofili & Watts, 1995) because she was looking for improvement in her work. She was feeling disenchanted because, as she said, she had been repeating the same lessons now for several years. She felt out of touch with the subject she was teaching and had decided, therefore, to re-visit and deepen her knowledge of constructivism. She was seeking change in herself. Prior to the course, she had undertaken some reading and attended a few conferences and courses on constructivism. In her initial interview for this study, Riso defined constructivism as to construct knowledge collectively, linking it with student's life

experience and aimed at restoring his or her social identity. She identified Vygotsky, Libaneo and Emilia Ferrero as constructivists. However, even though she held a clear idea of constructivism, she had not encountered and so was not aware of the work of Ausubel, Bruner, or Kelly and did not mention Piaget as a constructivist.

Riso's study was carried out in a state school, in an area surrounding Recife. The schools' classrooms are small and with little ventilation. There is a very small range of texts and resources–mostly just blackboard and chalk. Both the school environment and the students are impoverished. She developed her action research project in two Grade 5 classes, the first one with 42 children (aged 11 to 15). These students, despite their age, are already informal wage earners in order to help subsidise family incomes. The second class comprised 30 young adults (aged 18 to 25). These students attend evening classes because they work full-time during the day. Grade 5 represents a particular level of educational expectation regardless of chronological age.

During this first interview, before the course began, she was asked about the ways she introduces new topics in science. She responded by saying

> When I start, I select what I think is most easily understandable (...) On the one hand, it is easier to contextualise concepts with Year 7 students where the lesson content is –say– "water," "air" and "soil," because there is some very pollutant industry in the school neighbourhood. On the other hand, there is some content which is very hard to contextualise because it is very abstract, such as the "atom." It is abstract, even for me! In teaching "air" I use the example of this pollutant industry. The students list the diseases caused by pollution and I introduce the properties of air and ask about the composition of air. In trying to understand the composition of air they see that, apart from gases (which are the essential elements), there are other elements (dust, microbes...), depending on the area. So they can make conclusions on the relationship between industry and air pollution.
>
> My aim is for them to understand what I am teaching and at the same time to empower them in order to improve their life conditions. In reflecting on my own educational experience, I know how quickly knowledge escapes me. I thought"Gee, I learned and I forgot several times. What knowledge of mine has remained?" I learned that when teaching is contextualised and the students are active, then learning is better. However, when I just relay the information they do not retain anything. For example, last week they did a homework on air pollution. They collected information in groups and it was great. I could clearly see the knowledge they acquired what they had learned from the environment.

She was aware of her own performance with classes and of general political issues within the community. During her period of action research within her own classrooms, Riso created opportunities to establish and improve dialogue with pupils. Her concern was to foster critical thinking in order to enable student empowerment–she wanted they themselves to use critical thinking to help improve their life situations, to use their knowledge in order to change adverse social conditions. An example of this is her attempts to develop students' thinking by stimulating them to be critical of standard text books. In other words, requiring them to not accept science textbook information simply as authoritatively correct, without first submitting it to critical appraisal. This is a doubly difficult task given the formidable problems entailed in challenging the authority of an expert text, especially where this is in science because this is often perceived as the domain of incontrovertible fact.

Riso's intention was to investigate students' prior knowledge and stimulate debate between them in support of their own alternative concepts. She would then contrast emergent thinking with scientifically accepted knowledge and observe how the students might change their concepts after group discussions. She wanted students to be aware of their own thinking and to create the conditions for effective re-building in their thinking. In order to monitor this re-building, Riso used

several strategies for gathering data classroom observations, work sheets and interviews. She sought to compare approaches to learning between the two classes, by using different teaching methods with each. Working with the younger children in Class 1 raised a great number of questions. Riso directed these both towards drawing out pupils' own prior knowledge and to observations of the experiment as it was presented. In Class 2 with the young adults, Riso based her approach on Freire's (1972) notion of problem posing and–instead of beginning with a demonstration experiment–she based the lesson on their responses to a particular problem. The overall task for both classes was to construct concepts around the content of the lessons changes of state between solid, liquid and gas, in particular the concepts of fusion and vaporisation. During this time, of course, Riso was also monitoring her own thinking, and examining ways in which her own ideas, beliefs and commitments changed within the project she initiated.

Contrasts in the construction of knowledge for the two different ages, and through the two different approaches, were quite sharp. The students in Class 1, although younger, were rather undisciplined and this made the work difficult. They involved themselves with the activities only on few occasions, were generally dispersed around the class and paid scant attention to the subject matter for much of the time. This was certainly not true for the students of Class 2, which took place during the evening. Throughout her study she described them as demonstrating strong interest in finding solutions for the problems posed and were highly motivated when expressing or sharing their conclusions. These students integrated very well and developed a significant group consciousness and awareness, such that–at the end of the sessions–they felt they had fully participated in building knowledge.

In critical action research, the role of outside researchers can take several forms–in this case our collaboration with Riso helped to shape a series of questions: Why were the young adults in Class 2 more motivated? Why did learning seem more meaningful for them? Was it simply because they felt challenged by the problems posed, or was it due to the unaccustomed opportunity for expressing and discussing their own views? Could the involvement of the children in Class 1 be increased? What should be changed?

Riso's initial realisation was how difficult it is to teach abstract concepts to young students–it is difficult to contextualise issues where learners have no previous experience with which to relate the classroom material. She was very aware, too, both of her own knowledge limitations and the difficulties of managing large classes.

> The greatest difficulty I found was to work with a theme that embraced such diverse knowledge in chemistry and physics–besides my own biology. I realised that my own knowledge is linear in certain circumstances, which adds difficulty to exploring ways to help students to grasp knowledge. At certain times I felt as though I was disrupting in the process because I did not know how to offer options that might help them to choose their pathway. For example when a student claimed that vapour rising from the water was "smoke," I found it difficult to present options which would help her to arrive at different answers.

During her interviews Riso expressed concerns about developing critical awareness in the students, mainly related to citizenship, their rights and the development of a social conscience. It is evident from her interviews and her writing that she is convinced she has many improvements to make through, for example, introducing changes in her ways of talking to students and encouraging dialogue. She is changing her attitude towards students' alternative conceptions and giving voice to students. In short, she has began to see students as active subjects in the learning process and the importance of classroom discussion in knowledge construction. She is also painfully aware of the constraints under which she is working but she is still trying to understand ways of dealing with students thinking and learning even so.

> Step by step, we [teachers] are changing... the way we interact with the students ... even if not planned, the dialogue is changing. When we do something wrong it stabs at our consciousness! (...) My most important task is to develop consciousness ... critical conscience. The students need to know what they are studying and how this will affect their daily lives–as citizens, exactly what will be gained. I believe along these lines, the development of a social conscience, of rights. The other day we were beginning to form a view on space and a student asked"Why do I want to know about space?" So we stopped to discuss things, chatted amongst ourselves, and gradually they began to realise... it was interesting, that it is important. (...) But planning situations like that does not always work.

Later

> The number of hours I have to work is really bad. Each class has a different characteristic. In order to work well you should plan for each class. And I have not time. I work 120 hours, monthly for the Council and 150 hours for the State. 270 hours of teaching! Morning, afternoon and evening. 15 classes per day, Monday to Thursday. They pay for preparation time but it is not really possible. Only in the middle of the night! I get very tired and worn out. With 46 students, you notice the one who talks the most and understand things as they are in his or her mind. Interesting things happen that we do not have time to write down or make a note of ... I do not begin a class the way I used to anymore. I begin by talking, "why this and why that" ... many "why's."

Implications For Teacher Education

The extent to which one can generalise from a case such as this is an open question. By definition, a case study is "the examination of an instance in action" and is said to involve "some commitment to the study and portrayal of the idiosyncratic and the particular as legitimate in themselves" (Walker, 1993, p. 163.) However, the present case study was undertaken as part of a wider enquiry into the development of teachers' thinking and professional development (Jofili & Watts, 1995). It is intended to test the model we have discussed here against data collected from other teachers. Work in progress (Jofili, 1997) suggests there is evidence that the present model has wide impact, in ways which will prove illuminating to those involved in teaching in schools, colleges and universities. For example, the teachers involved in this course have continued to forge their own professional development and are keen to see the fruits of their action research work published and disseminated (currently in preparation). The course (with post-evaluative improvements) is to be repeated for further cohorts, using the initial group of teachers as contributors and tutors and, based on its success, the design and shape of the course is being taken up at neighbouring institutions.

Specifically, Riso's case allows us to conjure some implications for the development of teacher education within constructivist science education. We see our involvement with her, and her involvement with her students to be multi-layered. So, for example, as we reflected upon our own actions, she was reflecting on hers and prompting students to reflect on theirs. As awareness and the possibility of change grew, so did the need to promote change in particular directions.

From within our model, Riso's actions and comments have led us to four main issues which might be generaliseable beyond the case. The first, we suggest, is *clarity*. Within the general "fog" of teaching and learning, of schools and classrooms, it is important that teachers attain and retain clarity of intentions and purposes. Riso can be seen to working towards this as she surfaces from the constraints within which she works and develops awareness of the broad direction she wants to take, and the changes she wants to make. The second is *consistency*. Consistent with her beliefs and principles, with the models she has developed through the INSET course, Riso attempts to

justify and rationalise her approaches so that she retains a steadfast stance and style, both with each class and with herself. She was prepared to sustain her direction and not to duck issues with the younger class in the face of difficulties. Third, we suggest *openness*. Riso has been a model of openness as she has accounted for her actions, admitted to her frustrations and anxieties as well as successes and pleasures. She has been open and honest about the dilemmas and ambiguities she has faced, all of which lends integrity and authenticity to her vulnerability. The fourth is *communicativeness*. While we have described critical thinking in terms of an internal process, we have seen our own role as helping to bring awareness, the search for change, and the effecting of change to the surface. Riso has acknowledged this and made public and ably illustrated, her decisions, doubts, details and difficulties–responding actively to the scrutiny and questions of herself and others.

These pointers are not intended to be exhaustive but we see that the design of in-service provision and professional development for teachers–within science education or elsewhere–needs, even minimally, to encompass such features. To prepare a "constructivist course," designed to promote constructivism through constructivist approaches, requires clarity of purpose and procedure, and consistency of belief and principle. From our experience, the success of the course lay in its openness and the quality of communication with the participants. There were no sub-texts or hidden agendas and the participants shared in the direction and development of the programme even while they undertook the pursuit of their own studies thought their action research projects. This is not a common approach to teacher professional development and, while a Brazilian context might serve to highlight and dramatise some features of our work, we do believe that there are lessons here for many other contexts for learning across the world

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Correspondence: Zelia Jofili, Departmento de Educacao, Universidade Federal Rural de Pernambuco, Campus Universitario Dois Irmaos, 52.171-030, Recife - PE, Brazil.
Internet email: jofili@iteci.com.br

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