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Teacher Education and Process Skills Enhancement in the Science Technology Society Classroom

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Introduction

In this chapter, teacher education is considered from the perspective of science education which has always articulated the need to have students develop their thinking and reasoning skills. The processes that scientists use have been seen as essential to imparting learning in science courses. Over time, there have been a multitude of curriculum projects that have emphasized the process skills that scientists use for students to learn (Wilson and Livingston 1996). Thinking of teacher education in Africa in the digital age, there is a need to have some insight into some of these projects. According to Wilson and Livingston (1996:60), projects of the 1960s revisit and utilize the processes of science identified by scientists and incorporated into reform programmes of the 1960s. Most notable of these are the Benchmarks for Science Literacy: Project 2061 (AAAS 1993) and the National Science Education Standards (NCSESA 1993). The benchmarks describe these reforms as 'Habits of Mind' and 'The Nature of Science'. Although the reforms emphasize the processes of science, they neglect the same element that previous reforms have – the context for instructions. Specially, a context for learning that is relevant, seeks connections between concepts, shows science as a way of thinking, and works from the current conceptual understanding of students. One instructional movement is filling the void context while stressing the importance of the processes in sciences. The Science Technology Society (STS) instructional movement provides a context for the use of process skills used in science. The differences of the context between traditional process instruction and the STS process instruction have been contrasted by Yager and Roy (1993). It shows evidence in the student as learner, instead of receiver of science, in a context where there is an emphasis on process skills that students use as they resolve their own problems.

Science/Technology/Society (STS) is widely recognized as a major reform effort as correctives are sought around the globe to attain scientific literacy for all. The known school science is ineffective in producing students who are knowledgeable of the basic laws and theories known to scientists as accepted views of the workings of nature, nor are schools successful in producing students who think that such views of the universe are important and/or relevant to their own lives. Interestingly, technology, digital technology inclusive (how the human-made world operates), is seen as more important in contemporary time than science (how the natural world operates). And yet, it is rarely taught to all students across the elementary secondary school years. Science/Technology/Society has been called the current megatrend in science education (Roy 1984). Others have described it as a paradigm shift for the field of science education (Hart and Robottom 1990). It is the thinking; therefore, that process skills enhancement in the STS classroom with other skills such as critical thinking, education for critical thinking and action research in teacher education would be worthwhile in the digital age in the African educational system.

Process Skills and STS

Process skills and STS in the classroom enable students to learn science as against the traditional process where students receive science. Process skills with STS give prominence to context in which there is emphasis on process skills that students use as they resolve their own perceived problems in science courses. The comparisons given by Yager and Roy (1993) on traditional and process skills illustrate the difference. In the traditional process, science for students are skills scientists process; while in STS, science processes are skills students themselves can use. In the traditional settings, students see science processes as something to practice as a course requirement; but in STS, students see science processes as skills they need to refine and develop themselves more fully. In the traditional processes, teachers emphasize process skills that are not understood by students because these skills rarely contribute to actions in or even outside the course; while in STS, students readily see the relationship of science processes to their own actions. In the traditional process, students perceive science processes as abstract, glorified, unattainable skills; but in STS, students perceive science processes as a vital part of what they do in the science class. The argument is that, in previous reform initiatives, process science has been emphasized, but lacked the acknowledgment of the context for instruction. The students participated in the processes found in science, yet they had no bridge to other science or real-life experiences; but STS addresses the context in a meaningful way that sets the agenda for other instructional programmes.

It is obvious from African educational perspectives, as evident from the level of scientific and technological stance, that most secondary school students lack the intellectual skills in science and technology that would enable them to assume their roles in society, and that students need to cultivate scientific pattern of thinking, logical reasoning, curiosity, openness to new ideas, and skepticism in the evaluation of claims and arguments. One is left to conclude that students need to utilize the process skills characterizing science in order to understand and produce their own knowledge, which will ultimately allow them to participate actively in society. This is especially critical when contemporary life is bombarded daily with issues and problems based on science and technology. The ability to use the processes learned in science classes should provide students with a mechanism to evaluate, contemplate, and react to the changing world of today. In the STS process, we recognize that as science teachers attempt to conduct science, they are faced with decisions and considerations in using the processes characterizing science. These are decisions and considerations that are tied to the 'connectedness' of science process skills; which allow the processes connect to one another, the learner and the future problems, issues or investigators. Thus, the 'connectedness' should be addressed in a way that is developmentally appropriate, meaningful and relevant to the learners. In doing this, science educators become guides or facilitators of instruction. This entails monitoring students as they proceed through a problem, issue or investigation, providing information at critical moments and asking questions that bring about reflection on specific processes. This set up in science education may appear simplistic at first but the problem has a great deal of inherent complexity. Science educators could not possibly address all three levels of process connection in their instruction, unless instruction is centred round the student (Hurd 1991; Wilson and Livingston 1996).

By using the student as the template for classroom instruction, science processes are integrated through their actions. The teacher does not have to explain to each student which processes they are experiencing. As students proceed through an investigation, they select and use the processes they need. The nature of investigation blurs divisions of basic and integrated process skills. Basic process skills such as observing, classifying, communicating, measuring, using space/time relations, using numbers, and inferring and predicting, are used in conjunction with the integrated skills of controlling variables, interpreting data, formulating hypotheses, defining operationally, and experimenting. Furthermore, using process skills in a combined state supports the development of thinking skills, an initial tenet of using process skills. Baird and Borich (1987) and Padilla, Okey and Dillashaw (1983) have suggested that these skills are often viewed independently, yet they have been observed as correlating to one another and with Piaget's construct of formal reasoning. From this perspective, it is imperative that science educators in Africa bridge both the basic and integrated process skills into a student's repertoire of critical thinking which has been for a long time the concern of science educators generally. The final test of successful incorporation of a student would be the transfer of the skills to new and novel situations. Studies suggest that the longer the instructional periods of using the processes found in science, the greater the gains in the students' use of these process skills (Finley, Lawrenz and Heller 1992; Padilla, Okey and Garrard 1984). Specially, Padilla, Okey, and Garrard (1984) found that students who used integrated process skills for an extended duration of time showed growth in identifying variables and stating hypothesis. Roth and Roychoudhury (1993) found that authentic contexts supported the use of the process skills used in science. Thus, both duration and context play a role in the students' acquisition of basic and integrated science processes.

It is important to note that once these processes are 'incorporated', students will hopefully resort to them when they are faced with problems or investigations. Perkins and Salomon (1980) refer to transfer in problem solving as being a high or low road to transfer. The 'low road' depends on previous experience and similarity to previously practiced problems. The 'high road' depends on the learner's ability to abstract the problem. The learner must reflect and retrieve previous information and apply it to the new situation. Ultimately, the degree of transfer of process skills to new or novel situations may be dependent on previous experiences. When STS offers 'connectedness' to the process skills scientists engage in, students select problems, issues or investigations that are meaningful and relevant. It is hoped that as students engage in these investigations, they experience both basic and integrated process skills and assimilate and refine their repertoire of the skills found in science. The understanding is that, with the prolonged involvement of multiple STS opportunities, students create avenues of transfer to new situations. These three areas provide the 'connectedness' that is found in the science that Hurd (1991) promotes. African science educators must be aware that science is not an accumulation of knowledge about a particular domain, but competence in the use of process skills that are basic to all science (Roberts 1982). In this way, students who are involved in an STS problem, issue or investigation see the processes as a way of knowing and practicing science. In the broader scheme, students are provided with the skills to evaluate, contemplate and react to their world.

STS advocates find that the goals and instruction characterizing STS are congruent with the needs of the student. Students pursue investigations based on their own knowledge, cognitive, and interest level. Students work with current questions, problems and issues that are important, relevant and stated by them. As students act on these investigations in a manner that they select to follow, they utilize the processes that are found in science. This context allows students to become internally motivated to use the processes found in science, reflective about the need of science processes, and refine the processes that have been and will be used. African science teachers must be aware that successful practices for students require a positive affective domain within the instructional context. STS has been found to have a positive effect on students' attitudes toward science (McComas 1993). The implication for this is far-reaching when it comes to science instruction. STS provides a way to combat the negative feeling that students have had about science over the years (Jones Mullins, Raizen, Weiss and Weston 1992). An increase in the affective domain suggests that students find personal satisfaction in their participation in science. Students who enjoy and like science are more likely to engage in science (Simpson and Oliver 1990).

Research studies have confirmed that student involvements with STS strategies are superior to typical textbook/laboratory instruction in stimulating growth in science process skills (Iskandar 1991; Liu 1992; Mackinnu 1991). African science educators must appreciate that, in the past studies, students across all grades who have been involved in STS gained a further understanding of all basic science process skills. An evaluation of process skills can occur at the level of classroom or individual student skill within the class group. For example, Liu (1992) looked at fifteen teachers using both the STS approach and the traditional approach. Teachers who implemented the STS approach stimulated a significant difference ($P<0.05$) in student mastery of science process skills. Every STS classroom was significantly different in the obtainment of science process skills. Iskandar (1991) looked at the percentages of specific science processes that were demonstrated by students of seventeen teachers who conducted both STS and non-STS classes. She found that the differences in the mastery of science process skills were significantly different ($P< 0.01$) in favour of the STS approach. STS classrooms typically had process use that was twice what traditional classrooms had. Both studies used the Process Instrument from *Iowa Assessment Handbook* (Tamir, Yager, Kellerman and Blunck 1991). These studies support the idea that STS classrooms provide opportunities for students to refine and evolve the processes found in science. Students had a greater mastery and utilization of process skills in these classrooms as opposed to classrooms where traditional instructional methods were used. Furthermore, there were no demonstrated differences in the acquisition of processes between male and female (Wilson and Livingston 1996). STS process skills in science had its initiatives in United States, Britain, Netherlands, Japan, Australia and developing countries in the Pacific.

Education for Critical Thinking

Process skills and STS as knowledge and experience applied to practice call for judgement and judgement is rooted in critical thinking in all spheres of endeavour. According to Lipman (2007), wherever knowledge and experience are not merely possessed but applied to practice, we are likely to see clear instances of judgement. Architects, lawyers and doctors are professionals whose work constantly involves the making of judgements. The same is true of composers, painters and poets. This is also true of teachers, farmers and theoretical physicists as well; all of them have to make judgements as part of the practice of their occupations and their lives. We, as rational beings, because we make moral judgements when we are in moral situations. These are practical, productive and theoretical, as the philosopher would have put it. Insofar as we consistently make such judgements well, we can be said to behave wisely.

Good professional science teachers make good judgements about their own practice as well as about the subject matter of their practice. A good science teacher not only teaches well but also makes good judgements that provide a mechanism for the meaningful integration of the students with science concepts that enables them to develop a 'way of knowing' and a 'desire to know'. A judgement, then, is a determination of thinking, of speech, of action or of creation. These are likely to be good judgement if they are products of skillfully performed acts guided or facilitated by appropriate instruments and procedures.

Critical thinking – the result of education – is applied thinking. Therefore, it is not just process; it seeks to develop a product. This involves more than attaining understanding. It means producing something. It involves using knowledge to bring about reasonable change. Minimally, the product is a judgement and maximally it is putting that judgement into practice. There is another sense in which critical thinking needed in science teacher education in Africa would develop a product. It is the critical thinking which involves all responsible interpretation (the production of meaning) and in all responsible translation (the preservation of meaning). Critical thinking is thinking that facilitates judgements because it relies on criteria, is self-correcting and is sensitive to context (Lipman 2007: 427-8).

Critical Thinking Relies on Criteria

There seems to be an association between 'critical' and 'criteria' because they resemble each other and have a common ancestry. In the line of resemblance, we are familiar with book, music, poetry and film critics; and it is not uncommon to assume that those among them whose criticism is considered excellent are those who apply reliable criteria and therefore could be said to be critical. We are also aware of a relationship between criteria and judgements, for a criterion is often defined as 'a rule or principle utilized in the making of judgements' (Lipman 2007). It seems reasonable to conclude, therefore, that there is some logical connection between critical thinking and criteria and judgement. The connection, of course, is to be found in the fact that critical thinking is reliable thinking, and skills themselves cannot be defined without criteria by means of which allegedly skillful performances can be evaluated. So, critical thinking is reliable thinking that both employs criteria and can be assessed by appeal to criteria. For education in general, and science education in particular, it would not be out of the way to consider what uncritical thinking might be. Surely, uncritical thinking suggests thinking that is flabby, amorphous, arbitrary, specious, haphazard and unstructured (Lipman 2007). The fact that critical thinking can rely upon criteria suggests that it is well-founded, structured, reliable, defensible and convincing. How would this happen in an education system that appeals to critical thinking? As educators, whenever we make a knowledge claim or utter an opinion, we are vulnerable unless we can somehow back it up. In order to back up our knowledge claim or opinion, we are led to discover the connection between reason and criteria. Criteria are reasons; they are one kind of reason, a particularly reliable kind. When we are faced, as educators, to sort things out that are descriptive or evaluative – and these are two very different tasks – we have to use the most reliable reasons we can find, and these are classificatory and evaluative criteria. Criteria may or may not have a high level of public acceptance, but they have a high level of acceptance and respect in the community of expert inquirers. As teachers, the competent use of such respected reasons is a way of establishing the objectivity of our prescriptive, descriptive and evaluative judgements. Thus, architects will judge a building by employing such criteria as utility, safety and beauty; magistrates make judgements with the aid of such criteria as legality and illegality; educators use purposes, goals, aims, objectives, intuitions, insights, experimental findings, methods, etc., while critical thinkers rely on such time-tested criteria as validity, evidential warrant and consistency. Any area of practice – like the examples given above of architectural practice, judicial practice, teaching profession and cognitive practice – should be able to cite the criteria by which that practice or profession is guided. The intellectual rational domiciles we inhabit are often of flimsy construction; we can strengthen them by learning to reason more logically. But this will help little if the grounds and foundations upon which they rest are spongy. We need to rest our claims and opinions, as well as the rest of our thinking, upon a footing as firm as possible (Lipman 2007).

Critical Thinking is Self-corrective

There is an assumption that much human thinking moves along uncritically; that is, that human thought unrolls impressionistically, from association to association, with no concern for either truth or validity and with even less concern for the possibility that it might be erroneous. Among the many things we reflect upon is our own thinking. We can think about our own thinking, but we can do so in a way that is still quite uncritical. And so, granted that 'meta-cognition' is 'thinking about thinking', it needs not be equivalent to critical thinking. When Peirce (1931) discussed the connection between self-correcting inquiry, self-criticism and self-control as the most characteristic feature of inquiry that aims to discover its own weaknesses and rectify what is at fault in its own procedures – inquiry, then, is self-correcting. One of the most important advantages of converting the classroom into a community of inquiry with intellectual and moral integrity is that members of the community begin correcting each other's methods and procedures. The result is that insofar as each participant is able to internalize the methodology of the community as a whole, each is able to become self-correcting in his or her own thinking.

Critical Thinking and Context

We appreciate better critical thinking, displaying sensitivity to context when we consider an astute copyeditor going over an essay prior to publication, who makes innumerable corrections justifiable by appeals to recognized rules of grammar and spelling. To him or her, idiosyncratic spellings are rejected in favour of uniformity, as are grammatical irregularities. But stylistic idiosyncrasies on the author's part may be treated with considerably greater tolerance and sensitivity. This is because the editor knows that the style is not a matter of writing mechanics; it has to do with the context of what is being written as well as with the person of the author. It is therefore important to recognize thinking that is sensitive to context to involve: a) exceptional or irregular circumstances; b) special limitations, contingencies or constraints wherein normally acceptable reasoning might find itself prohibited; c) overall configurations; d) the possibility that evidence is atypical; and e) the possibility that some meanings do not translate from one context or domain to another.

Action Research and Teacher Education

The appeal for process skills and STS in science teacher education can be realized in an educational system only if action research is integrated into teacher education in Africa as elsewhere on the globe. Research is a cognitive act, as it teaches us to think at a higher level in the knowledge-based community. From this perspective, we can appropriate the action research movement in teaching to further our critical postmodernism vision of school reform and serve as a pedagogical strategy to help teachers break out of the prison of modernist thinking. Experience has shown that critical action researchers equipped with an understanding of research methodologies truly operate on their own recognizance, as they stake their claim to independence from the oppressive regime of educational leadership. According to Kincheloe (1993), action research that is critical meets five requirements: (a) it rejects positivistic notions of rationality, objectivity and truth – critical action research assumes that methods and issues of research are always political in character; (b) critical action researchers are aware of their own value commitments, the value commitments of others, and the values promoted by the dominant culture. In other words, one of the main concerns of critical action research involves the exposure of the relationship between personal values and practice; (c) critical action researchers are aware of the social construction of professional consciousness; (d) critical action researchers attempt to uncover those aspects of the dominant social order that undermine our effort to pursue emancipatory goals; (e) critical action research is always conceived in relation to practice – it exists to improve practice.

With these requirements in mind, critical action research is a consummate democratic act, as it enables teachers to determine the conditions of their own work. Critical action research facilitates the attempt of teachers to organize themselves into communities of researchers dedicated to emancipatory experiences for themselves and their students. When teachers unite with students and community members in an attempt to ask serious questions about what is taught, how it is taught and what should constitute the goals of a school, not only is critical self-refection promoted, but group decision-making also becomes a reality (Carr and Kemmis 1986:221-23; Giroux and Aronowitz 1985:81). As action research fights techno-teaching and procedural thinking, it seeks unity with critical democratic groups outside the school. Using their research skills to identify subjugated knowledge in the local community, teachers as researchers become cultural workers who develop unique post-formal pockets of people who come to think about cognition as a political activity. Educational reform of any type will not work unless teachers are empowered. Action research is an empty idea; it becomes another educational triviality unless teachers make it a part of their lives andtheir belief systems. This explains why top-down educational reforms fail – critical reform cannot be mandated without teachers' consent. Any kind of reform predicated on a view of teachers as de-skilled functionaries who carry out the orders of the superiors cannot succeed. In a dominant culture that has not valued self-reflection on the part of its teacher professionals, action research becomes an oppositional activity as it pushes professionals in a variety of fields to reconsider their assumptions (Greene 1988). Information produced by post-modern inquiry is a self-conscious social text produced by a plethora of mutually informing contexts (McLaren 1992).

It is assumed that humans are active agents whose reflective self-analysis and knowledge of the world leads to action. Action research is the logical extension of critical theory in that it provides the apparatus for the human species to look at itself. Critical action that is aware of postmodern perspectives on the production of subjectivity, the context of hyper-reality, and post-Jaynesian connected consciousness can contribute to the socio-cognitive emancipation of men and women. Such a socio-cognitive emancipation is the first step in our cognitive resolution, our post-formal effort to see the world and ourselves from new civilization as Africans through our educational system. Based on a democratic dialogue, an awareness of historical moment, and a passionate commitment to the voice of the oppressed, the post-formal insurrection re-defines research, in the process producing knowledge between the crack information previously swept under the rug, particularly in the sciences.

Conclusion

The views of science as historically rooted and as an enterprise affected by society and culture have not influenced science education in Africa. Otherwise, how would anyone explain that in the twenty-first century world, no African country has been able to graduate from developing country to an emerging nation? This is the case despite the serious reform efforts by some of the African countries, since independence, to develop new curriculum materials and to provide corresponding teacher education. This reality of the situation of science education in Africa, even in this digital age, informed the suggestion for process skills and STS that have the potential for influencing science education since they focus on changing the goals and content of science teaching in ways that will link science to social concerns. It is hoped that through process skills enhancement in the STS classroom, critical thinking and action research in the African teacher education system, students would be equipped with meaningful integration of science concepts and develop a way of knowing, desire to know and practice science as art. Our approach would awaken a meaningful context that has students building their own knowledge base; create complex challenges that would have students using basic and integrated processes of science; lead to reflection about the consequences of procedural decisions, continuing development of higher-order thinking skills and opportunities for transfer of processes to new and novel situations.

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