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Students' Understanding of the Concept of "Current": Language, Models, Definitions

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Interviews conducted by one of us (Z.J.) with thirty first-year students at the University of Fort Hare (Ciskei, South Africa), whose home language is Xhosa, show that although these students had received extensive instruction about the concept of *current*, including its formal definition, and its application to simple D.C. circuits, they held alternative conceptions concerning *current* and electrical conduction of a kind previously noted by many researchers. The way the students use the particle model suggests that it serves only to reinforce their existing conceptions. A highly significant feature of these interviews is that in none of them does a student make any reference to the formal concept of current as amount *of charge flowing per unit time*. We therefore suggest that relevant teaching strategies should give major attention to clarifying quantitative as well as qualitative ideas about *flow*, and that because of the baggage of alternative meaning attached to the word *current*, the use of the latter term as the concept name should be delayed as long as possible in the teaching sequence. We contend that unless these things are done, students will be seriously handicapped in trying to integrate their measurements and observations of phenomena in D.C. circuits into a meaningful conceptual structure.

1. INTRODUCTION

This paper presents reflections of one of the authors (H.H.) on aspects of research data obtained by the other as part of an investigation of conceptions of electric current held by first-year students of physics at the University of Fort Hare. During the time this work was carried out, all the students at the university were Black; all could speak English, the official medium of instruction at the university, but their mother tongue was one of the indigenous languages of Southern Africa. It has long been the case that, owing to the deficiencies of the country's educational system, such students arrive at the university inadequately prepared, with a limited command of essential mathematical tools, poor familiarity with the kind of modern technology that is taken for granted by white students, and an approach to the physical sciences that relies heavily on memorization and rote learning. One may reasonably expect that not only would such students have many or all the difficulties with understanding electricity that have been identified amongst other groups of students by various researchers; they might well have problems uniquely associated with their background and experience.

Diagnostic testing carried out on such students in 1979 and 1980 indicated that substantial numbers of them might have difficulty in mastering the elementary theory of direct-current circuits; specifically, that they might be confused about the concepts of *current* and *potential difference* and their relationship to *energy*, and about the role of *resistors* in simple circuits. In first-year practical classes, the opportunity was taken to give students tasks related to D.C. circuits, which required them to make simple observations and to record and comment on them. Students' responses to these tasks were made the basis of informal interviews with them, in which they were able to expand upon their written comments. In these sessions it was very evident that correct observations were often incorrectly explained, and that the explanations offered might give hints of the alternative framework of concepts held by the student.

These considerations led to the decision that an appropriate way to extend the preliminary investigation was to conduct personal interviews with a smaller number of a preselected spectrum of students, along similar lines to those described by Osborne and Gilbert (1980). In the interviews, the student did most of the talking and the interviewer-instructor tried to probe the student's understanding with short, open-ended questions such as "Can you tell me the reason for this?", :"Why do you say that?", "How do you know?", "How did you work that one out?". The subjects were left in no doubt that they were not being "tested" and that what they said would not count against them in any way. The interviews were allowed to flow naturally. Only after the interview subjects had had their spontaneous say did the interviewer probe further in order to test hypotheses suggested by the subjects' responses. In this way, we hoped to avoid the danger of influencing the subjects' reasoning. Care was also taken to ensure that the next question followed reasonably smoothly from the subject's response to the previous one. Although the interviewer would have a pattern of questions in mind, this was flexible enough to permit adaptation to the circumstances ruling at the moment. The interviewer tried always to convey the impression that the subjects' views were treated with respect. That non-standard or unanticipated responses were obtained from time to time suggests that the subjects did not feel unduly constrained by the interviews. Indeed, the majority of the students interviewed were very keen on follow-up interviews. It seems that they felt that this might help them solve their difficulties with concepts. Participation in the initial interviews also made it easier for them to consult the interviewer about other aspects of physics.

An advantage of this investigation is that the interviewer spoke the students' home language (Xhosa), so that the subjects could switch easily and spontaneously to this language when they felt that they could express themselves more clearly in this way. This was especially important in this research, as it had appeared in the preliminary investigation that some of the students' problems with these aspects of physics might have had linguistic origins. (*Force*, *energy* and *power* are all rendered as *amandla* in Xhosa, and the same word is used for both *electricity* and *lightning* in most vernacular languages in Southern Africa.)

To summarize: the interviews in the main investigation were carried out to try to establish the nature and possible origins of students' alternative conceptions about aspects of electrical circuits and the underlying concepts and principles. The emphasis was on identifying the alternative conceptions and obtaining a qualitative description of the conceptual models that emerge, rather than to accumulate reliable data about how widely particular alternative conceptions are held.

The main investigation was carried out on random samples of first-year students during the years 1980, 1982, 1983 and 1984. The students were enrolled in the Physics 1M (Medical and Biology) and Physics 1A (Ancillary) courses at the University of Fort Hare. All students interviewed had received formal teaching in Physical Science at High School; in other words, they had been exposed to the elementary theory of direct-current electrical circuits, including applications of Ohm's Law to single loop circuits, and to the fundamentals of electrostatics, including Coulomb's Law and the concept of the electric field. (It should be noted here that the "official" approach to the teaching of current electricity, laid down in the syllabus and followed in all recommended textbooks, makes liberal use of the particle model of electrical conduction.)

Each student was individually interviewed. Pictures or diagrams of simple electrical circuits, or actual electrical apparatus, were used as focal points for the discussion. The interviews, which usually lasted about forty minutes, were audio taped for later analysis. Interview subjects were either volunteers, or students who visited the instructor seeking help with their work and who the agreed to be interviewed.

2. RESULTS

In what follows, we concentrate on responses in interviews which appear to reveal students' ideas of electric *current*.. Quoted responses are grouped under headings which give the key ideas that emerged from the interviews.

(a) *Current can be* ***stationary****, as when it is stored in a battery not connected to anything*.

"There is current electricity in the battery but it is not flowing".

"If the battery is fully charged then there is a current in it even if it is not connected to an outside circuit".

"I think that current is stored in the battery so that when the bulb is connected it will light".

(b) *Current is only present in the* ***outside circuit****, not in the battery itself.*

"I would say that there is no current in the battery although there is a current in the outside circuit .... because the chemicals are separated."

(c) *The electrons in the wires move with very high velocity.*

"By the time you switch off, the electrons, which are of a very high velocity, will have already moved to the battery."

"The electrons move with the speed of light ... they are always moving at the same speed."

(d) *An electron in a wire will push its neighbour along.*

"One electron here [i.e. at the negative terminal] pushes one electron in the wire which will push another etc. until one electron enters the positive pole."

"Because of the energy they just got from the battery the electrons cause the electrons in the wire to move on."

(e) *Resistance slows the electrons down.*

"...on passing through the resistor the electrons lose some of their kinetic energy."

"...the current loses kinetic energy on passing through the resistor".

(f) *When currents combine, the electrons associated with each will maintain their separate velocities.*

[Interviewer: What happens when the electrons come to the junction of these two parts (the lamp and the resistor)?] (Fig. 1)

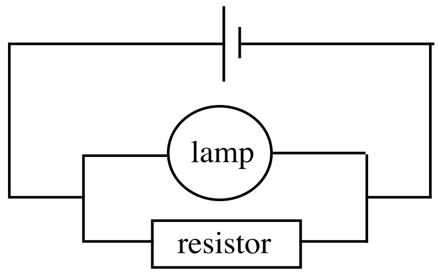

Fig. 1

"...the currents in the lamp and resistor will be moving with different velocities in these parts. [Beyond the junction] they will have a combined [velocity] or mixture of velocities."

(g) *Electrons may be lost on passing through a resistor*.

"Since there is a resistor the current is going to part with some electrons here... sort of gain more electrons from the battery".

"Often the current loses some of its electrons on passing through a resistor."

(h) *Electrons are "used" in circuit elements, which may result in a loss of electrons*.

"The electrons, when they get there they turn into light... the electricity which goes to the lamp is being given off by the lamp as light."

"Some of the electrons are used and those that go through, will be used afterwards in this part."

(i) *Current is used up in circuit elements*.

"The current is less because some of the electric current is lost [in the lamp] ... because some of the electric current has been transformed into another form of energy which is l light."

"...some current has been used in lighting the lamp ...[because] a thing which has more resistance uses more current."

[This idea emerged in a number of interviews.]

(j) *At a junction between a single conductor and a pair of parallel conductors* [see fig. 1 above], *the currents in the parallel branches are equal, regardless of the resistance in each branch.*

"Because these are in parallel then the current is divided equally here.... [Why?] ...since they are parallel."

"...when the current goes here [i.e. to the junction], one half goes to this side, the other half goes the other way. [What happened if the resistance in this branch is halved?]...the current here will still be half.."

"No! ..the distribution of the current does not depend on the value of the resistors."

(k) When asked to make predictions about circuits such as the one shown in fig. 2 below,

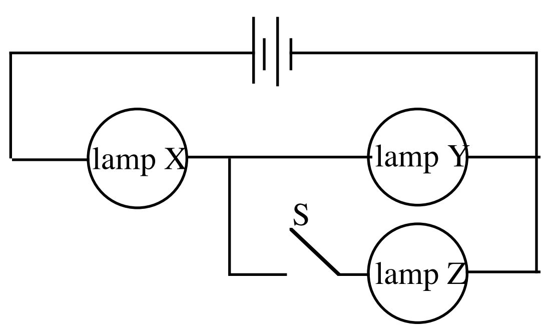

Fig. 2

many would work from the premises noted above, namely that the current was "used up" as it passed through a succession of resistors, and that it would be divided equally in two parallel branches. To these, some added the idea that the introduction of new circuit elements in parallel with existing ones does not alter the current[s] in the latter. The response below illustrates this approach:

"Y and Z will have the same brightness ... but lower than X. The brightness of X will remain the same [as before the switch S was put on] since it is the same current flowing in Y and Z ... as was in Y originally. (The current in X has not altered because the switch S is now on.)"

3. IMPLICATIONS OF RESULTS

These responses show that this population shares some, at least, of the alternative conceptions concerning *current* that have been noted by a host of researchers in this field. This is significant, in that it suggests that the problems previously identified may straddle cultural boundaries. Also, it is surely significant that these alternative conceptions surface in a group of students whose exposure to everyday use of electrical energy and even to the use of the jargon of electricity in conversation and casual reading is much more limited than that of many of the students known to hold such conceptions. In our view, there are other important findings to be noted; in this paper, we shall examine the responses of our sample of students in the light of the *content of the instruction* they had received. We regard this as important as these students are relatively mature, and their encounters with this material in the classroom were recent and likely to be quite fresh in their memory. It is thus conceivable that their contributions to the interviews could shed valuable light on the effectiveness of the instruction they had received. In what follows, we shall consider the influence, if any , on students' thinking of two features of that instruction, namely, the use of *the particle model of electrical conduction* and *the formal definition of current*.

There are at least two potential advantages of using the *particle model* in teaching elementary electricity. The model can help the student to form a mental picture of what is happening beneath the surface of the observable phenomena, so that the abstract concepts used to describe and analyze those phenomena can seem more real; it can also be used to predict phenomena, at least in a qualitative way. The above-quoted responses certainly show that these students are willing to use the particle model to support their interpretations or predictions of phenomena in simple circuits. This willingness does not appear to be accompanied by an increased understanding of the phenomena. Instead, the model has been adapted by individual students to suit their preconceived ideas of what is happening. In the last resort, all they seem to have gained from their acquaintance with the particle model is an enhanced vocabulary, the new terms in which are as little understood as the old. Thus, what one takes to be the ultimate pedagogical objective in using this model , namely, a clearer view of the subject matter, has simply not been achieved in the case of any of the students interviewed.

A clue to the lack of any positive influence of the particle model on these students' thinking is to be found in a striking *negative* feature of their responses in the interviews: the complete absence of any mention of the formal definition of *current*. At no point does any of the students invoke anything resembling an "official" statement of what the concept means in order to defend a proposition or clarify an argument. The closest these interview subjects came to correct use of *current* was in substituting an appropriate quantity for "i" in the relationship "V = iR"; but here, their understanding seemed to be limited to the recognition that the symbol "i" denoted *current*.. From this, we may deduce that the content of the definition has literally no meaning for them. We will consider below why this might be; but in the meantime, we might note that constructive use of the particle model depends critically on an appreciation by the user of the concept of *flow* , which is central to the definition of *current*..

No doubt the concept of *current* favoured by our sample of students differs from one student to the next. What seems to be common is the idea that "current" is something that can circulate through the elements of a circuit in the right circumstances. This is, of course, irreconcilable with the very definition of the concept, which asserts that *current* is how much charge is passing a given reference point per unit time.; in other words, it is a *measure* of *flow of charge*. The latter message seems not even to be received by these students, let alone understood. Even their limited acquaintance with what is "out there" regarding *current* is evidently enough to inhibit them from internalizing, as opposed to learning by rote, the formal definition of the concept. This is not so remarkable when one looks at the challenge faced by the novice required to understand what is claimed by instructors to be happening in even the simplest of circuits, such as a light bulb connected to a battery by two pieces of wire. What the novice *sees* in this case is that the bulb glows with constant brightness. On this phenomenon, the instructor places the following interpretation :-

> *Charge* is circulating through battery, wires and bulb, which constitute a *circuit*.. In the bulb, *energy* is being exchanged between the charge carriers and the bulk of the filament of the bulb, causing the latter to heat up and to glow. At any point in this circuit, the amount of charge passing it per unit time, or the *current*, is the same as at any other point . [Jargon words have been italicized.]

This is, of course, by no means all that can be said about this particular circuit, but it is enough to make the point that there is a lot here for a newcomer to the theory to take in - and indeed to take on trust, since so much of what is being claimed about what is happening lies well beyond direct observation. Kenneth Strike has justly asserted that "Nature does not wear her concepts on her sleeve" (Strike 1983); we contend that a simple electrical circuit does not wear its concepts on its sleeve either. There is a substantial gap between what can be directly perceived and the highly abstract conceptual apparatus needed to interpret the phenomena fruitfully. Instruction has to play a key role in bridging this gap . The mass of data obtained by researchers on alternative conceptions of *current electricity* suggests that even in the presence of instruction, the knowledge students may construct is likely to have limited usefulness at best; what they might do if left to their own devices is best left to the imagination. At the same time, the research data, including those reported in this paper, imply strongly that traditional techniques of instruction have failed in their aims. Can one deduce any strategies for better instruction in electricity from this steadily accumulating experience? We believe that it is possible to suggest some guidelines which, at the very least, are worth trying out in the classroom.

4. **TOWARDS GUIDELINES FOR IMPROVED INSTRUCTION**

(a) The language of instruction

We have implied above that it is unrealistic to expect students to construct viable conceptions of current unaided. We have also noted that even when the instructor dispenses correct information, this may have little or no influence on the concepts with which the student is comfortable. Evidently powerful counter influences have been at work in promoting the construction of alternative conceptions, and we are unlikely to achieve much in the way of improvement by intervention if we do not pay some attention to those counter influences. Whatever is presented to students as new knowledge will not be received in a vacuum. Inevitably, they will try to link it with what is already there; in the case of direct-current circuits, what is "already there" undoubtedly includes everyday usage of the relevant terminology. Of the terms already familiar to the student, *electricity* and *current* are, we suggest, the most pervasive and influential; for many students, one suspects that these terms may be inseparable in content. When students hear the word "current" from the lips of an instructor, they are likely to associate it with the meaning it already has for them. Any doubts they might have about the validity of that association will very likely be dispelled when they hear instructors use such expressions as "Pass a current through..." or "the current flowing here.." . (For the teacher to say "The current in...." does not remove the difficulty, as this can reinforce the idea that there is current in a battery even when the latter is not connected to anything.) This linguistic area can be a minefield, even for experienced researchers. Consider the following quotation from a review by Shipstone (Shipstone 1985):-

> "The current is a flow of charge around the circuit and, is conserved, which is to say that the current entering any element of the circuit must be equal to that leaving, and currents at junctions divide and recombine so that none is lost or gained."

Those familiar and comfortable with the underlying concepts will have no difficulty either in understanding this passage or accepting that it is fundamentally correct. But close inspection of the statement reveals that the word "current" is being used in at least three different senses. There is the qualitative, almost colloquial sense of the word ("current is a flow of charge round the circuit"); there is also the quantitative sense ("current ... is conserved") , and in clarifying the meaning of "conserved" in this context ("...the current entering any element...must be equal to that leaving"), the author seems to be implying that this quantitative concept is something which can enter and leave a circuit element. Of course, this part of the quotation is meant to be interpreted as "the amount of charge entering any element in a given time is the same as that leaving it". Were beginners to read the original statement, they could be pardoned for treating it as reinforcement of the notion that "current " is something that circulates in a circuit. Shipstone is not addressing his remarks to such an audience, and we are not suggesting that he would advocate an approach to teaching the subject in which the instructor use the term "current" in three different senses in one sentence. Instead, we have used his summing-up to show how easy it is to make potentially confusing statements on the subject .

The problem instructors or authors of textbooks face here has been well summed up by Ernst von Glasersfeld:-

> "As seasoned users of language, we all tend to develop an unwarranted faith in the efficacy of linguistic communication. We act as though it could be taken for granted that the words we utter will automatically call forth in the listener the particular concepts and relations we wanted to 'express'. We tend to delude ourselves that speech 'conveys' ideas or mental representations. But words, be they spoken or written, do not convey anything. They can only call forth what is already there" (von Glasersfeld 1985).

In the light of all this, what is the concerned instructor to do? If the word "current" is so bedevilled by its everyday association with "something that flows", to the extent that its proper definition is ignored by students when it really counts, what options remain open? We believe that on the linguistic side, there is a solution, which we will recommend below. Before we turn to that, we need to note that , as Holcomb (Holcomb 1992) has stressed, even the "official" definition of *current*, in the form in which it is often given ("*current* is rate of flow of charge") is not without a linguistic problem of its own. Specifically, does the term *flow* in scientific usage imply "*rate* at which the material [fluid, charge, ..] is passing by" , in which case "rate of flow of charge" is a tautology loaded with power to confuse (compare the phrase "high rate of speed", beloved of newspaper reporters and police spokespersons)? Perhaps the community of physics educators could look into the matter. In any event, the concern raised by Holcomb is a salutary reminder that any statement purporting to be a definition needs careful scrutiny before it is taken on board. The issue of how one defines *current* is fundamental to our enterprise, and our guidelines include a suggestion for bypassing the problem presented by "rate of flow".

(b) *Current* and the concept of flow

We have suggested above that a reason for students effectively ignoring the official definition of *current* in their thinking about circuits is that the term itself conjures up for them a meaning quite different from that embodied in the definition. It is conceivable that the everyday meaning might not be quite so influential if the *content* of the definition were more closely related to students' experience than it appears to be. Of key importance here is the concept of *flow*, both qualitative and quantitative. We suspect that in many high school curricula, this concept receives short shrift, so that when students encounter it in a vital definition in an unfamiliar context, they have little or no sense of what is being laid before them; there is nothing in their existing repertoire of concepts with which to link the new idea. It is no good our bewailing the prevalence in students' thinking of deviant conceptions or models of current, if our instruction has failed to address the challenges presented by *flow* itself, and students have been inadequately prepared to deal quantitatively with *any* kind of flow, let alone the invisible kind which instructors tell them is happening in electrical circuits.

(c) Some suggestions

It is not our intention in this paper to present a detailed alternative teaching approach to *current*.. In recent years, a number of such approaches have been suggested (e.g. Steinberg 1987, Arons 1990, Shaffer and McDermott 1992), which take research on students' alternative conceptions into account. We offer here certain suggestions arising out of the considerations outlined above which, we feel, could strengthen a variety of otherwise sound teaching approaches.

(i) Because of the central role of *flow*, we advocate that it be given ample space in any attempt to lay the groundwork for understanding *current*, with liberal use of tangible examples, such as the flow of liquids or traffic. ("Cash flow" might not be such a good idea, for various reasons.) Both the qualitative and quantitative aspects need to be stressed. It is clear from the protocols obtained at the University of Fort Hare that none of the students concerned was able to distinguish clearly between the notion of "something flowing" and a *measure* of that flow at some point in a circuit. That distinction needs first to be clarified in reference to everyday examples of flow. Many present-day curricula in introductory physics do not make provision for discussion of how to *measure* the flow of anything, except charge. If students find themselves able to accept notions like "amount of stuff passing in a given time" or , more correctly, "amount of stuff passing per unit time", *and* can be persuaded that this quantity can be the same at different points along the line of flow, they *might* be willing to apply these ideas to a postulated "flow of charge" in a circuit. In our view, there is no need to use more formal terminology to name the measure of "flow of charge" than the above expressions. By sticking to the latter, one is both spelling out what one is talking about *and* avoiding any difficulties connected with the term "rate". Some instructors might want to use the expression "flow of charge" to represent this measure, once they are convinced that the quantitative aspect is well enough understood.

(ii) If ever there were a concept which demands rigorous application of Arons's precept, "Idea first, name afterwards" (Arons 1990), this is surely it. Indeed, we suggest postponing the actual use of the term "current" as late as possible. This suggestion may sound simple-minded, but we put it forward here in all seriousness as a realistic way of avoiding the undesirable associations of the familiar word. As to what to put in its place, we suggest that it would do no harm and possibly a great deal of good to use an appropriate *phrase* to refer to the concept whenever it is needed. (One wonders just how much confusion is sown or maintained in students' minds by the prevailing tendency in the teaching of mechanics to use "tension" to denote "force" exerted by the string".) If it is felt that the students really are comfortable with the notion of *flow of charge* used quantitatively, then this phrase can be made to do duty for "current"; otherwise, longer expressions like "charge flowing by per unit time" can be pressed into service.

5. CONCLUSION

Current is a classic case of a concept invented or constructed to describe and make sense of a class of physical phenomena. There is now overwhelming evidence that what students have constructed for themselves as bearing the label "current" bears but little resemblance to the accepted meaning of the term, and that their own views are strongly resistant to instruction. The particle model of electrical conduction, far from helping students to overcome conceptual hurdles, is instead adapted by them to strengthen their existing concepts. Our own research leads us to believe that students' problems in this area derive partly from the failure of our instruction to take into account the difficulties associated with the *meaning* of *current*, and from a failure to recognize that for many students, the word "current" could actually be an impediment to understanding the concept it labels. We suggest accordingly that instruction could be more effective if it included substantial attention to the concept of *flow*, and if the use of term "current" were avoided until the last possible moment.

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