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The electronic spreadsheet and cognitive skills in inquiry oriented biology

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Abstract

From a cognitive point of view, a spreadsheet is essentially a tool which enables learners to express intentions by means of formal instructions to a machine, and to assess the consequences of their instructions. While the objectives of "computer-integrated" science teaching remain essentially the same as those of today's traditional science teaching, the integration of the computer into the science teaching-learning processes requires, and provides opportunities to enhance, cognitive skills related to what could be called aspects of the scientific language and culture. These cognitive skills refer to both declarative and procedural knowledge.

Keywords

Secondary education, instruction (CAI), computer literacy, spreadsheet, teaching methods

1 INTRODUCTION

Students learn biology in various situations. The most common one is the more or less frontal lesson in the classroom, where the students may interact with a teacher. Such an interaction gives the students opportunities to benefit from the unique potential of the teachers' main tool, their brain. The adaptive flexibility of the human brain enables the teachers to understand the students' questions, ideas, intentions or motivations even when the students are unable to express them explicitly and clearly, and also to adapt their responses to the needs of the individual students. Teachers *understand,* but their teaching activity is severely hampered by their limitations: as human beings, they act slowly, the number of mental or physical operations which they, or their students, can perform in a limited amount of time is very limited. Consequently, they find it difficult to take care efficiently of every student in the class and to cope with certain objectives which are central to science education. This is why they must look for new partners in their teaching activity, thus creating different learning situations. Such a new partner is the electronic spreadsheet. The spreadsheet is radically different from the human teacher: it works very quickly. It can process with great speed a tremendous amount of data, draw nearly instant graphs, etc. However, its versatility is very limited, since it does not understand half-formulated intentions or ill-expressed instructions. Furthermore, as an open tool, it does not guide the user, but reacts to its instructions. When interacting with a spreadsheet, *all* the students must therefore know very clearly *what* they wish the computer to do for them, and *why*. It is also imperative that they know *how* to express their intentions in the form of very formal and precise instructions, in order to be "understood" by the computer. Because of all these characteristics, the spreadsheet, when used within the framework of carefully designed teaching-learning strategies, can become one of the biology teachers' most powerful partners: it provides opportunities to enhance the development of cognitive skills which are related to the language and culture of scientific inquiry, i.e., to one of the main objectives of modern biological education. Working definitions of a few terms must now be briefly stated, to clarify the educational approach which underlies this paper.

Carefully designed teaching-learning strategies

Although there is no necessary isomorphism between learning *of* inquiry and learning *by* inquiry, strategies of guided inquiry are potentially powerful because they are consistent with strategies of conceptual development or change. Concerning conceptual change, the essential characteristics of the spreadsheet, as an open tool, are: a) the above mentioned requirement that the learners formulate their ideas very clearly, that they make "their implicit reasoning explicit"; and b) the fact that, owing to its "What .. If ..." capacities, and to its efficiency in the computation, organisation and presentation of data, it gives the learners real opportunities to assess "the consequences of their reasoning" (Driver and Scanlon, 1989).

Objectives of modern biological education

Biology is an experimental science, which obtains knowledge mainly by means of hypothetico-deductive methods of scientific inquiry. It is also essentially a quantitative-statistical science, based on samples of populations, and variance is a built-in characteristic of such populations. The verification of hypotheses in biology, on the basis of empirically gathered data, must therefore account not only for central values, such as means, but also for variance. The development of some basic cognitive skills necessary to any empirical-quantitative-statistical "inquiry into life", is considered to be a necessary condition for any meaningful understanding of biology, and has become one of the main objectives of biology education. Such cognitive skills are also essential to the learning of the technologies which confer to biology its socio-human context, such as medicine, agriculture and modern bio-technologies.

Cognitive skills

In the context of the spreadsheet-assisted development of inquiry skills, Royer, Cisero and Carlo's (1993) working definition of cognitive skills, as consisting of "a mixture of specific facts and procedures to use those facts. ... made up of both declarative and procedural knowledge ... acquired through training and /or experience", is especially appropriate. According to this approach, cognitive skills, through the stages of their acquisition, are transformed "from an activity that is slow and highly taxing on the cognitive system to an automated set of activities that may place virtually no load on the system". Intellectual skills are *tools* which involve conceptual, or principled knowledge, *and* its utilisation, and in Brown, Collins and Duguid's (1989) terms, people who use them actively may "build an increasingly rich implicit understanding" not only of the tools themselves, but also of "the world in which they use the tools". Because of its swiftness in the performance of a wide variety of operations, the spreadsheet provides the students with opportunities to personally and intensively experience various methods and techniques of manipulation of data, so that they may gain the amount of experience and involvement necessary to the development of intuitions and "rich implicit understanding" about cognitive inquiry skills. In other words, they may develop a true, first-hand knowledge of intellectual skills which are part and parcel of the language and the culture of the scientific community.

2 COGNITIVE SKILLS IN SPREADSHEET-INTEGRATED LEARNING SITUATIONS

In order to make an open tool as the spreadsheet "work' for them, the learners must give it instructions. These instructions, which are conveyed to the computer by means of the keyboard and/or the mouse, are the concepts of the language used in the *dialogue* which takes place between the tool and its user (Dreyfus, Feinstein and Mazouz, 1993). Knowing how to give an instruction to the computer (which keys to push and in which order) without understanding the meaning of the instruction is not equivalent to "speaking" to the computer. Pushing a key is akin to emitting a word; giving *intentionally* a meaningful instruction to the computer by pushing a key, is equivalent to conveying specific meanings by means of words. It follows that the technical use of the keyboards should be taught as a language (putting words on meanings) within the context of activities which confer meanings to the words. In this context, a cognitive skill may be regarded to have been acquired when the learner *understands* the concept behind instructions to the computer, and is able to use this concept *purposefully* and *meaningfully*, on *relevant* occasions. The successful use of a cognitive skill to perform a task consists of the following steps:

a) understanding the task;
b) selecting, out of a pool of potentially relevant and well understood instructions, the correct one/s or the most suitable one/s (knowing why instruction X, and also why not Y, or why X rather than Y);
c) using the instruction correctly (in the sense of applying correctly a principle);
d) using the right "words", i.e., the right keys, to convey the instruction (the technical aspect of the use of the keyboard);
e) reading and interpreting correctly the computer's response;
f) deciding if the computer's activity corresponds to the intentions of the learner/user (did the computer do what I intended it to do?), and if the instruction was the right one, or the best one.

It can be seen that the purely technical aspect of the use of a spreadsheet (step d) represents only a small part of the activity of the learners. Actually, it is also the only part about which good advice is routinely given to learners, provided that they know what to look for, in the "help" programs and in manuals. It can also be seen that steps a) to c) refer to the *intentions* of the learner, step d) is the *translation* of those intentions into the language of the spreadsheet, and in steps e) and f), the learner is involved in the *interpretation* and the assessment of outcomes. It is worth noting that in this respect, the situation of the learners who use a spreadsheet is quite different from that of the paper and pencil (without computer) learners. On one hand, when working without a computer, the learners have to perform personally *all* the often very tedious steps of the task, but on the other hand, they remain all the time in full control of the events. When using a spreadsheet, the students do not actually carry out personally any practical part of the task. They do not compute and do not *draw* graphs: they do define the attributes of the graph, and give appropriate instructions to the computer, but after pushing the "enter" key, they *loose control. The computer works now for them*, extremely quickly, without giving them any opportunity or any possibility to follow or control the phases of the construction of the output. There are however various reasons why the instructions may have been both inaccurate and intelligible to the computer: the learners may have been unaware of the fact that the instruction they gave was not the one they believed they were giving (misunderstanding of the nature of the instruction), or they may have given the right instruction, but made an error (wrong definition of a range, a field, a variable, etc.). In such cases, the students, who had not been warned by the computer, may have remained unaware of the fact that what they obtained was what they had actually *asked for*, and *only* what they had asked for, but not what they had *intended* to ask for. Steps e) and f) are therefore indispensable, and often very intellectually demanding. The requirement that the learners assess the congruence between their intentions and the outcomes of their work is quite specific to learning situations which involve open tools such as spreadsheets, and is invaluable in the context of strategies of conceptual development, which put a high priority on the learners' clarification of their own ideas and intentions. Indeed students who are able to realise that something is wrong in the type of results obtained, display a good conception of the nature of the task they are involved in, and vice versa.

The spreadsheet learning situation imposes other specific cognitive demands on the learners, or, in other words, gives them other opportunities to develop intellectual skills. The learners must organise the data in such a way as to enable the spreadsheet to "work" with maximal efficiency. They must learn to "think computer", or in this case, more specifically, "think spreadsheet", i.e., to adapt their reasoning to the opportunities offered by the spreadsheet and to its limitations. "Thinking spreadsheet" when organising the data means being able to *predict* the consequences of the organisation on the way instructions will be carried out, a skill which requires a sound understanding of the nature of the operations performed. To exemplify, let us consider a simple and classical experiment.

Bits of potatoes are immersed in distilled water for 20 minutes, then weighed and transferred to sugar solutions of various concentrations. After an hour, they are weighed again. Because of osmotic pressures, the tissues will lose water, and thus weight. The students compute the weight loss as percentages of the original weight, then compute averages and produce graphs which show the relation between the concentration of the solution and the weight loss. Ten groups of students perform the experiment on ten concentrations, i.e., the data will include 100 original weights, 100 weights at the end of the experiment, and the results must show 100 percentages. If the data are efficiently arranged, the 100 percentages may be computed by means of *one* computation (one formula) and *one* "Copy" instruction. Students who have found the most efficient pattern of organisation must have been able firstly to *conceive* it, then to *select* it out of a number of possibilities, i.e., to foresee the consequences of "copying" a mathematical formula to the whole range of data. They must have had a very good idea of the nature of both the required mathematical operation and the "copy" instruction. Since there are other, less elegant and less efficient ways to obtain successfully the correct results, the students may have tried several possibilities, using the "What ... If ..." facilities of the spreadsheet, but even those trials required the skills necessary to ascertain which of the possibilities did best perform the task in congruence with their intentions. Obviously, misunderstandings about the nature of the "copy" instruction in such a case, or about the source and target ranges, or technical mistakes in the typing of the instructions (for example, a5 instead of a6), may have brought about, without any warning, *intelligible but inaccurate* instructions, with their consequences. Actually, many students who appear to have mastered the skills necessary for the use of a spreadsheet, possess only the technical skills needed to happily make the spreadsheet work, but have not achieved the intellectual skills necessary to assess the appropriateness and consequences of their instructions.

A second look at the experiment will show the main characteristics of biological research, as can be demonstrated in the school laboratory: the results are obtained empirically, and the mathematical formula is used to find relations between variables, not to predict them. Each group obtains different results, so that the findings will be based on the values of both means and variance. The spreadsheet gives the students opportunities to develop insights into the nature of these values, because it enables them to cope with true samples in a reasonable amount of time. The spreadsheet is used as used by scientists, which means that it does not "*teach*" the students, but *provides them with opportunities to learn.*

To sum up: inquiry oriented activities in which a spreadsheet is incorporated include the following phases, in sequences and at frequencies which vary:

Phase 1: Understanding the problem and predicting. This phase starts with the presentation of the problem and continues until the students have proposed tentative solutions to the problem, i.e., hypotheses. This is the phase at which students clarify their knowledge and ideas and make them explicit.

Phase 2: Planning. In this phase, the students suggest experimental designs to verify their hypotheses.

Phase 3: Declaration of intentions. The students make explicit the ways in which they intend to process data and results with the spreadsheet.

After phase 3, they perform the experiment or are given empirical data and results, as obtained by scientists.

Phase 4. Processing of the data. This phase includes all the mathematical, logical and organisational operations which are performed on the data, by means of the spreadsheet.

Phase 5. Assessing the congruence between the actual processing of the data and the intentions. This phase may involve modifications in the processing and partial reorganisation of the data.

Phase 6. Analysis of results; comparison between expected and obtained results. This is the phase at which new knowledge is inferred from the results and conceptual change is expected to occur. (In the above mentioned potato experiment, the students are very seldom able to predict at phase 1 the actual pattern of results.)

The integration of the spreadsheet has made the inquiry activity different in several respects from the same activity when implemented without a spreadsheet: inserted into the strategy of inquiry learning, phases 3 and 5, which are new, and phase 4, which is different, account for the treatment of the various types of spreadsheet-related intellectual skills.

3 TYPES OF COGNITIVE SKILLS

The potential of the spreadsheet concerning cognitive skills, especially the most obvious ones, such as graphing skills, has been abundantly inventoried. We will only give a few examples of skills which demonstrate a specific, and somewhat neglected, contribution of the spreadsheet.

As a *computing machine*, the spreadsheet may contribute to the development of an intuitive grasping of the meaning and use of mathematical or statistical concepts, crucial to biological inquiry (for example, means, variance, distribution, significant differences, regression, correlation, plotting, best line, etc.). This can be done at a relatively early age (Dreyfus and Levy, 1996), about notions such as mean and distribution (for instance, the intuitive understanding that the sum of the deviations from the mean is always 0, developed when students try without success to make this sum change).

When used as a tool to switch from one *representation* of data to another one (from table to graph, for instance), the spreadsheet gives opportunities to develop the skills necessary to: a) grasp the nature of various representations (for example, a graph is not a drawing); and b) convey the same global message by means of different methods of representation (students often do not realise that the story told by their table is not exactly similar to that told by their graph, in spite of their intentions).

When used as a tool to *organise* data the spreadsheet is related to important skills of processing of data and of communication, i.e., of transmission of messages (efficient presentation of data, results, relations, etc.).

When the spreadsheet is used mainly as a *database*, the formulation of queries and the sorting of data to verify hypotheses is related to crucial inquiry skills: the "If .. Then .." and the "And ...Or" ways of thinking. More specifically, students learn to try to refute an hypothesis. For example: out of a database on birds, they try to refute the hypotheses "if they have wings, they are birds", "if they are birds, they have wings" and "only if they are birds, they have wings", or quantitative hypotheses of the type "If it is an X, then it is bigger than Y".

4 CONCLUSIONS

From a cognitive point of view, a spreadsheet is essentially a tool which enables learners to express intentions by means of formal instructions to a machine, and to assess the consequences of their instructions. Because of the opportunities with which it provides the teachers and the students along the enquiring sequence "prediction, intentions, processing, assessing, comparing, concluding", the electronic spreadsheet may be an invaluable tool in the development of inquiry related cognitive skills. It should however be clear that the cognitive skills required for, and developed by means of, the use of the spreadsheet are not equivalent to the technical skills which make its use possible. Whereas *technical* skills may be developed by the frequent use of a spreadsheet, the development of cognitive skills *depends* on educational strategies which involve the learner in an interactive dialogue with the machine.

5 REFERENCES

Brown, J.S., Collins, A. and Duguid, P. (1989) Situated cognition and the culture of learning. *Educational Researcher,* **18**, 32-42.

Dreyfus, A., Feinstein, B. and Mazouz, Y. (1993) Keyboard instructions as concepts of the language of quantitative biology in spreadsheet-assisted activities. *Journal of Biological Education,* **27**, 39-46.

Dreyfus, A. and Levy, O. (1996) Are the notion of mean and related concepts too difficult for 5th and 6th grade biology students? *European Journal of Teacher Education,* in press.

Driver, R. and Scanlon, E. (1989) Conceptual change in science. *Journal of Computer Assisted Learning,* **5**, 25-36.

Royer, J.M., Cisero, C.A. and Carlo, M.S. (1993) Techniques and procedures for assessing cognitive skills. *Review of Educational Research,* **63**, 201-243.

6 BIOGRAPHY

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