INFORMATION TECHNOLOGY (IT) TO CHANGE BIOLOGY TEACHING, OR TEACHING IT-CHANGED BIOLOGY ?

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ABSTRACT : Information technologies (IT) can be used to support teaching. On the other hand, Biology is deeply changing with IT, creating massive amounts of new data and new tools, available through the web. New ways of building knowledge emerge. This could cause information overload. However these authentic tools and data can be an opportunity: rather than popularize science, helping students to understand complexity and letting them become not only passive consumers, but active creators of worthwhile knowledge. A few design rules for designing science teaching will be presented.

RÉSUMÉ Les TIC sont souvent vues comme un moyen de développer l'enseignement. Mais elles modifient profondément la biologie, produisant d'énormes masses de données, et de nouveaux outils. De nouvelles manières de pratiquer la biologie émergent et sont disponibles librement. Cette surabondance peut être vue comme accablante ou comme une opportunité – en exploitant ces outils et ces données authentiques – de développer des stratégies de construction de savoirs et l'autonomie les étudiants.

IT AND BIOLOGY EDUCATION

First I would like to draw a distinction between educational use of IT for teaching science – new ways of teaching unchanged science, and all the **IT-induced changes of science** – new science. I will develop more about this which I call this *IT enhanced Biology* (in French I have coined the expression BIST[1])

A few words on the use of IT in education. There has been considerable research into the use of IT for science education [2-9]. In a historic perspective, I see 3 levels of use of IT in education: at first great efforts were put into training students and teachers to master the use of computers, and the mastery of the machine was seen as a prerequisite to any educational use of IT. After that good education would follow… It didn't.

Later it appeared that the focus should be on subject-specific integration into teaching and learning (at TECFA we came to name this in French iTIC). The learning of technologies in context of disciplinary education is now beginning to be recognized as much more efficient. [10]. This second level is becoming the main approach today.

The third level, mostly subject-independent, is about knowledge building [4, 9, 11] : the use of cognitive IT tools in educational designs to enhance learning. I will later focus most specifically on this third level of IT use in biology education.

BIOLOGY TEACHING WITH ICT

Before we look into IT-induced change of Biology, let us have a quick look at the second level of integration. Biology teaching with ICT can be thought of under different angles: classical approaches cataloging by type of tools such as word processors or web-page editors don't appear to me very fecund in education. I would suggest thinking (a) in terms of participants and roles, (b) in terms of type of document involved, (c) in terms of information flux.

THINKING ABOUT IT IN TERMS OF PARTICIPANTS / ROLES

Thinking in terms of participants and roles will for example distinguish use of a simulation by the teacher from students exploring the same piece of simulation software. Indeed, the student's effective role when seeing the teacher demo a simulation might be passive watching

and is very similar to watching a film, whereas an exploration could put into action very different cognitive processes and lead to different learning gains. Similarly presentation software could be used by students in a role of journalists as a means of writing and confronting their emerging ideas with others in a debate, or the same software could be allow diffusing the teacher's knowledge to students in a passive role.
The underpinnings of this distinction are that the mental activities of the students, and therefore their learning, critically depends on their roles and that these should be the focus rather than the tools used.

THINKING ABOUT IT IN TERMS OF TYPE OF DOCUMENT INVOLVED

The document involved in IT use can be of different types. It quite often is a form of publication such as a text or a presentation, and the focus would the be on the document itself: the teacher might be proud of it's scientific, structural, graphical, … qualities. Good documents would be seen as the sign of good teaching. In fact sometimes it seems teachers think the document *is* the teaching.
The IT document involved could be a production of the students, such as in Project-Based-Learning : a poster, a brochure, a website, a Blog, … that the students proudly show to a public of parents or the school community. Here again the focus is most often on the document itself. Good student documents are seen as a sign of good learning.
Another type of document, used for example in Inquiry-Based-Learning (IBL), where the document isn't important in itself, but *supports* the learning, as a sort of cognitive scaffold, [12] will be discussed later.
The underpinnings of this distinction are that the type of document being created determines quite a bit the mental activities involved, and that the production goal (what this document will be used for, to whom it will be presented or by whom it will be used) determines even more the motivation of students in the activity.

THINKING ABOUT IT IN TERMS OF INFORMATION FLUX.

In a communication perspective we will examine who created the document involved in IT use and to whom it is addressed. Certainly the most common case in education, at least in teacher training at university of Geneva [13], is teacher-produced documents distributed to students-recipients. Thinking about other possible cases helps in imagining other rich designs

for improving education: documents could be created by students for other students such as in problem-based learning, or when students communicate with other students in another part of the world about their environment, etc.
An interesting case is when the students are involved in creating documents for the class community such as in Knowledge-Building communities [14]. The knowledge improvement process relies on computer documents, shared between students, which support the learning and constitute a useful trace of their work, or for example, a brochure they will use fore revising before exams.

EDUCATIVE TECHNOLOGIES ? CAN TECHNOLOGIES *EDUCATE*?

The expression "Educational *Technologies"* is quite often misunderstood: it seems to imply that the technology itself might educate, that a whiteboard might improve teaching of biology, that some data-acquisition kit might in itself improve the educational outcomes of experiments in biology labs, or that wikis might miraculously improve student's understanding. The effectiveness of such technology has been shown to be highly dependant on the way the activities are managed [15, 16]. Technologies can allow new designs and support student activities that improve science education, but only if the part they play in the design is well thought and integrated.

SCIENCE IS A WAY OF BUILDING KNOWLEDGE

Before we move on to the change within biology, let's define biosciences. According to [17] their defining characteristics are:
(1) "**that all knowledge is related to observation or experiment**,
(2) they are a family of methods and disciplines grouped around the investigation of life processes and the interrelationships of living organisms,
(3) they **exist in an environment of current hypotheses rather than certainty,**
(4) they include disciplines in which rapid change is happening,
(5) they are essentially practical and experimental subjects " (highlights mine)
In this paper, we will specially refer to educational implications of two of these: that all knowledge is based on data and that any scientific knowledge is rooted in current hypothesis rather than definitive truth.

IT- ENHANCED BIOLOGY

Similarly to other aspects of our society [18], biology is undergoing a major paradigm change under the influence of information technology [1]. Information processing has become a crucial and increasing share of all biologists' work.

Referred to nowadays as *In vivo,* Biology was mostly an ontological and specific discipline up until about mid 20th century involved in naming and classifying species. The second half of the 20th century saw the emergence of reductionist approaches to biology with "how does it work ?" the main question and led to a strong confrontation of *In vivo* and *In vitro* biology. The debate is mostly over and both approaches coexist. Now a new approach is emerging, on which the biologist I surveyed informally spend up to 70 % of their time: sometimes dubbed *in silico*, I will call it It-Enhanced Biology. So we now live in world of *In vivo* + *In vitro* + *In silico* !

It's not just a few new tools : Biology itself changes : the questions faced, the strategies, the competencies needed are very different :

> "We had searched for many years and found 1 human pheromone receptor. When the human genome became available, in one week we found 110 new genes ! Then we went back to the bench to analyze their activity with classical techniques. " [19] Bio-Review

After having read and analyzed quite a bit of literature both scientific and educational, I have identified 4 aspects of IT-enhanced Biology that seem relevant to education:

- Bioinformatics and other genome or sequence linked data: 'Omics .
- Other biological databases such as georefereced data in Geographical Information Systems (GIS). Ecologists, botanists and zoologists nowadays spend a major part of their time managing, processing and extracting new knowledge.
- Systems Biology and Simulations.
- **Knowledge building in an infodense world:** the ability to locate, use, and evaluate information [20]

I will discuss in this article principally the consequences of the fourth aspect of change on biology education.

IT-ENHANCED BIOLOGY : VIRTUAL OR MORE AUTHENTIC ?

Because computers have allowed the development of a large array of representations of reality such as enhanced images and videos, simulations, etc. one might think of IT in education inserting a layer of virtuality between reality and students?

However, as we move towards a biology centered around information, a DNA sequence in a database [21] is in fact the most authentic data available. When working with DNA, protein and other biological data, information *is* what it's about nowadays.

Three levels of Authenticity can be defined [22] as :

(a) use of authentic data, such as that available from scientific Databases : Uniprot, Mapviewer, BookShelf, etc
(b) use of authentic scientific tools such as BLAST, sequence alignement (Clustalw) or tree building software (Phylogeny), species distribution tools such as FaunaEuropea, or botanical phytotyping such as SOPHY,
(c) authentic epistemology. This third level implies students are involved research. Some researchers [4] believe it is possible to involve students in true knowledge improvement. As the data and the tools for today's biology are often available through the web, an opportunity for authentic activities is available for education. Therefore, it is worth discussing the opportunity of teaching IT-enhanced biology.

Biology works with ever increasing amounts of data, and although IT has caused this avalanche of information, I will argue that we need IT - enhanced tools to manage all this information, in education too. And this implies new tools, new competencies, new educational strategies [23]

And of course new teacher competencies, which have been extensively described in the Bio2010 report [23] : Quantitative biology, Information management, specific knowledge about databases, etc.

I will here discuss these in more general terms: developing information fluency.

These approaches have been developed in a few educational designs, including : IBL for high school biology teaching, popularized science analyzing for knowledge building strategies, biology teacher training strategies in Geneva (See doiop.com/bist)

AN EXAMPLE DISCUSSED: EMPOWERING STUDENTS TO BUILD KNOWLEDGE IN AND INFODENSE ENVIRONNMENT.

This design is of the IBL type, for high school biology teaching. The students were high school biology students of final year (18-19 year old) students in a biology major course in Geneva. The learning objectives were: better *scientific thinking:* rather than rote learning a

science of conclusions, developing an in-depth understanding of biological processes.
Autonomy in learning: empowering students to build knowledge in infodense environments, and standard or better achievement at regular exams.
The research objectives were to develop a teaching design for IT-enhanced Biology, and to refine design rules.
The inquiry based learning (IBL) model is an iterative building of knowledge - quite similar to science - where questions guide a structured process of writing and confronting knowledge by students.
The curriculum is divided in chapters, and for each chapter, students worked in groups of 4 on a subtopic, chosen to be slightly overlapping. Each group was responsible for one document: a Wiki page in which questions were collected and answers were recorded as they were found. The pages were progressively structured according to a template. The whole class produced a collection of Wiki pages that were printed at the end of each chapter as a brochure of 20-30 pages. This brochure was framed as help for the students themselves to prepare exams. During lessons, students spent a large share of their time searching in books, experimenting, observing, etc to answer assigned questions. Once the student have searched for a few hours, they present to the whole class the state of their current knowledge, stating the questions they pursue, how they found answers, what they know, what they don't know yet and how they plan to learn that. This leads to refining the questions, re-defining the sub-topics each group tackles and new emerging questions. The groups then deepen investigation and the cycle is repeated. Most often, 2 cycles could be achieved and the last cycle ends with a final presentation, (which was more geared on final understanding of knowledge than the first). Resources include a general biology textbook, specialized academic books, experimental equipment, field observations, selected Internet on-line-books or resources and Internet access to many resources such as Wikipedia.

[insert figure 1 from file *IBL-cycle-bioEd08.jpg*]
Figure 1 : A schema of the IBL design : students typically go through 2 cycles improving and sharing their knowledge about one chapter.

I would like to stress a few points of this design : during the year, progressively the students were encouraged to find answers themselves as the teacher refrained from answering and

suggested appropriate resources to find answers. The students were explicitly told this is to encourage autonomy as the following year they would be at university.
After about 6 hours (1 1/2 week) they expose their current – necessarily unfinished – knowledge to others and discuss, reframe their questions. This intermediary presentation is an important step in sharing knowledge between groups and crucially in deciding which questions to pursue. A framework for this was inspired by [24] : what we want to know, what we have learned, what we need to know and how we plan to find it. With these refined questions a new cycle starts. This presentation is not given marks, but the tutor asses and helps focusing the research while he final presentation is formally assessed. Usually two such cycles last 3 weeks.

HOW TO TEACH STUDENTS TO IMPROVE KNOWLEDGE IN BIOLOGY ?

I will now discuss a few theoretical underpinnings of this design. It is designed to engage students in meaningful inquiry activity, as this has been shown to develop deep understanding e.g. [15, 25-28].
Iteratively writing a significant document has been shown to help translate activities into knowledge building[29, 30] and adequate computer supported writing (here the Wiki) is therefore expected [12] to help building knowledge in infodense environments.
Use of a shared writing space (Wiki) could lead to idea confrontation and socio-cognitive conflict [31-35] should help developing in-depth understanding.
Presenting and confronting current knowledge at early stages [8] should favor synthesis, interconnections and therefore help learning to work with ideas "in an environment of current hypotheses rather than certainty".
The teacher in the role of a tutor and knowledge authority found in experiment or resources [8]
should develop scientific knowledge building, i.e. "that all knowledge is related to observation or experiment" by letting students validate ideas by their ability to explain data or stand up to criticism.

DATA COLLECTION METHODS

One major source of data is Wiki history data : the Wiki server automatically records practically all versions of the text, and which allows retrieving previous states of the pages. These records are called "history" and can be used for research purposes as well as for pedagogy, such as comparing versions to help students become aware of progress. Students also answered questionnaires, during their learning process, and later on, at the university. These questionnaires gave information on the perceptions of students about their knowledge, the learning methods and the design. Over the years, a few in-training teachers attended the course and kept journals or other records. These gave a different point of view on the events in the classroom, and were discussed. They helped formulate and to adjust some of the conjectures. They also gave opportunities to view the teacher as a variable of the system rather than as the main cause of what happens in class.

Time frame of analysis: The history of each Wiki document could be analyzed for changes of the same group working on the same document across a few weeks: we call this stratigraphic analysis. As each class –and the teacher - works through the whole year, the successive Wiki documents recorded could be compared: we call this yearlong analysis. Over the years, data accumulated of successive iterations of Wiki documents about the same curriculum gave information about the evolution of the design: we call this longitudinal analysis. The uses of various resources along stratigraphic, yearlong, and longitudinal axis were partly recorded, and the use of specialized academic books, Internet resources, etc. can be retrieved from the bibliographic references in the Wiki pages.

SELECTED RESULTS

The results show that this design effectively allows students to produce texts with in-depth explanations of complex biological processes, based on information that they have found in appropriate resources such as textbooks. Analysis of text produced in the Wiki shows quality increases along the year: more explanation and not only descriptive texts, deeper explanations, more synthetic.

Students showed autonomy in finding these explanations in books or other resources rather than from the teacher, and most declared they felt the balance between scaffolding and autonomy adequate at the end of the year (3.0 on a scale of 4; σ 1.07)

They showed their capacity to find appropriate information in an infodense environment by writing texts that are effectively a synthesis of diverse complex resources, for example

moving past Wikipedia and finding out how T4 Lymphocytes interact with other immune cells to fight viruses in an academic online Textbook [36].
They said in a questionnaire at the end of the year that intermediary presentations were most efficient for those presenting, clarifying their ideas, and assessing their understanding, whereas the iterative writing in the Wiki was seen as an efficient way to structure and build an understanding. They were aware that questions drive the process and are crucial to focus the inquiry.
They stated in the questionnaire that they felt well prepared (3 on a scale of 4; σ 0.5) to learn in the face of information overload and felt capable of selecting and assessing the quality of sources.
They felt at ease (2.8 on a scale of 4; σ .82) with the responsibility of validating their ideas, and most of them appreciated the freedom (3.1 on a scale of 4; σ 1.16).
Results at exams could not be statistically compared because of comparative data unavailability, but anecdotal evidence (jury sayings) suggests they were equivalent or better. Cooperative work was considered an important competence but most still find it difficult. The workload was considered a lot, but worthwhile by most.
One year afterwards, once at university students were invited to a questionnaire and declared they had acquired effective strategies to face the complex knowledge learning challenges that medical, engineer, or business studies imply. Some students mentioned their surprise at the depth of understanding they had achieved "I didn't imagine I'd remember so much one year later, […] for example when we studied the nervous system in my medical studies, I was astonished with how much I remembered, and how deep we had delved into each subject." Medical student, 1st year university, personal translation.
"Although I am not in Biology but in Human sciences, this method helped me structure and plan my work and mange group tasks. I would say it's not only learning biology, but also a scheme for working!" Sociology student, 2nd year university, personal translation.
"What struck me is not so much the quantity, but the life span of what we learned" 1st year University student, personal translation.
These results are of course not statistically undisputable, as those who replied might well be the more satisfied students, so there might well be a bias, but their number (about half of the students depending on years) suggests this design worked for many students.

MATRIOSCHKA RUSSIAN DOLL MODEL

One design rule that has already emerged is about how to transform learning objectives into student inquiry. As designers we see objectives first, whereas students see assignments as goals. Questions are often proposed to students to focus inquiry. But students rarely engage thoroughly in questions that are imposed on them. Consequently aligning the assignments and tasks so that objectives are attained is difficult. I propose here an approach to designing educational projects that tries to align objectives and student motivation. It acknowledges that students' engagement starts with the production worked on, and works from there to questions and to inquiry. So the design should work from the objectives to finding questions which contain those objectives (first doll-in-second-doll) and then find some worthwhile document to engage the students into inquiry about those questions (the questions are embedded in the document: third doll in second doll). So student engagement goes from document to questions to inquiry and designing goes backwards from objectives to questions to document.

[insert figure 2 from file matrioshka-model-en.jpg]

Figure 2 : Matrioschka Russian doll model for inquiry design

A FEW OTHER DESIGN RULES

The analysis of this design confirms that with adequate scaffolding students can learn strategies for building knowledge in infodense environments and manage complex information. Therefore empowering students to face complex information rather than popularizing is a feasible strategy, and a critical one today we would argue.

Designing activities in which the authority of validating knowledge is progressively transferred to the students as they learn to assess resources and confront different sources of information is feasible and probably desirable.

This of course redefines the role of the teacher and the less prestigious statute of tutor rather than expert and knowledge dispenser that this implies is probably not easily accepted. An interesting question is the interactions of a less prestigious teacher statute with learner attitudes in such designs.

CONCLUSION

Our data support the conclusion that Wiki-supported IBL designs can be developed to empower students with strategies for facing the complex infodense environments that characterize current biology. It appears that the focus should be on inquiry directed by questions that the students engage in, and progressively transferring the responsibility of validating information to the students. They showed signs of working satisfactorily with scientific knowledge that "exists in an environment of current hypotheses rather than certainty ". Producing meaningful documents is central to motivate and engage students. An iterative writing process structured with confrontations of knowledge as it is built, can be a very productive cognitive task.

An approach based on knowledge improvement in the sense of Carl Bereiter [4] was illuminating: showing how to give sense to school tasks by putting them in perspective of the main activity students will face for many years: building and producing better knowledge in various forms such as writing, models, etc.

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