NEW OPPORTUNITIES FOR AUTHENTICITY IN A WORLD OF CHANGING BIOLOGY.

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Abstract:

Biology now produces massive genomic and other data, new ways of building knowledge rely ever more on the processing of data through information technology. Biological data such as DNA sequences and analysis tools are widely accessible via Internet and qualify as authentic. They offer new opportunities to explore, test and validate hypotheses in numerous fields of biology and allow students to engage in the same cognitive processes as hands-on biology. Science is also a process of building knowledge by confronting ideas, discussing their certainty, their links to the data that they are built on and their source. New authentic resources are available to all, raising the possibility for students to practice the authentic scientific process of validating knowledge.

Framing authenticity in terms of resources and students activities, we have refined designs for building scientific knowledge, principally a Wiki-supported Inquiry-Based Learning design in information-dense environments of various degrees of authenticity.

We will discuss the influence of resources, their authenticity, on the development of scientific knowledge and strategies.

Results include an increase in epistemic complexity of student-produced text, a shift towards using resources of increasing authenticity and autonomy in validating information. Some authenticity-linked design features, and generalizabilty will be discussed.

1. Introduction

The importance of authenticity in education has been recognized long ago (Dewey, 1911; Freinet, 1960), but efforts towards it in school have come upon difficulties such as didactic transposition (Chevallard, 1991). We will attempt defining a few aspects of authenticity and discuss how authenticity-related features of IT-supported teaching designs might influence learning science doing. We adopted a Design Based Research framework.

1.1. What is authenticity?

In a most general sense "authenticity" is some similarity of education processes with those practiced by "real people". What reference activity is isomorphic with what educational process is not often clearly stated. Authenticity might simply refer to "ordinary practices of the culture" (Brown, Collins, & Duguid, 1989). Generally it implicitly refers to scientist and their activities, questions and methods: the "social practice of reference" (Martinand, 1989) for "doing biology".
We will discuss authenticity in terms of the resources, tools, environment provided on one hand and concentrate on authenticity of the learner's processes, activities and productions on the other.
We identify three authenticity levels modified from (The Cognition and Technology Group at Vanderbilt, 1990) A first level involves the facts: true research data is considered more authentic than carefully selected, educationally polished data. A second level considers the tools and methods: involving students in similar tasks, with the same tools and methods as professionals use. A third level involves students in "doing real research"; creating new knowledge.

1.2. What is science ?

Here we define Science as a method for validating knowledge (W. A. Sandoval & Morrison, 2000) based on confrontation with data and alternative explanations. Indeed the process of science relies on argument and debate to validate knowledge, however they are virtually absent from science education (Osborne, 2010).
Knowledge being scientific doesn't so much depend on it's subject (about animals, ecosystems or sequences) but on that scientific information clearly making reference to its sources, to the data on which it is based, to it's justification and to its certainty. These are metacognitive characteristics. (Bromme, Pieschl, & Stahl, 2008).
For example the "fact" that humans and chimpanzees differ by 1.23% can be called scientific once is established i) the source of this figure (The Chimpanzee Sequencing and Analysis Consortium, 2005a), ii) the justification by methods used (difference in terms of nucleotide substitutions) iii) the links to the data (Full genome (The Chimpanzee Sequencing and Analysis Consortium, 2005b) accessible in MapViewer), iv) the comparison with other methods for establishing similarities (DNA hybridization, gene homology, SNP identity, sequence identity, etc.). A person who "scientifically knows" can infer from this structure and warrants the certainty of this information, and put it in perspective.
In contrast this difference of 1.23% is not scientific when given as « true » by reference to an authority (Nature, textbook or the teacher).
When a student states "1.23%", one cannot distinguish scientific from naive knowledge.
"Doing science" in education should focus on getting students to build these properties of their own knowledge, not just learning facts.

1.3. Authentic literature?

Many authors have explored the authentic potential of non-school-literature: Adapted Primary Literature (APL) (Falk, Brill, & Yarden, 2008; Yarden, et al., 2009) or Modified Anchored Instruction' (MAI) (Mueller, Kuhn, Mueller, & Vogt, sous presse 2010) and show important effects on motivation and learning outcomes.

Authenticity of resources is not binary, but a gradient from school books, popularized sensationalist magazines, to primary literature, and the use of slightly more authentic resources can have educational effects. Sequences accessible through web portals such as UniProt or Mapviewer books from the NIH database Bookshelf are considered more authentic than the same data illustrated in textbooks.

1.4. A changing biology's authentic tools ?

Biology is deeply changing under the influence of Information Technology (IT)(NRC, 2003; Pevzner & Shamir, 2009): massive amounts of new data (genomics, botanical, biogeographical, etc.) are available, new tools are offered (sequence searching and comparing, phylogenetic tools, etc) and most scientists spend a large part of their time (more than half according to our informal survey) building biological knowledge with IT "*in silico biology*".

In fact data processing often qualifies alone as research in high-impact journals. For example a much-cited article, comparing the human and the chimpanzee genome for evidence of recent change, (Pollard, et al., 2006) uses freely available genomic data produced by others, didn't carry out any wet lab experiment in terms of manipulating apparatus, living material, or reagents. The knowledge built is real, but results from IT processing. This new way of creating knowledge using data from public databases is a considerable change of the reference activity of "doing biology". It is largely adopted by researchers (Strasser, 2006), but appears mostly ignored by education (Lombard, 2007).

With respect to education, we distinguish (Lombard, 2008) four aspects of IT-Enhanced Biology:

i) Bioinformatics and other genome or sequence-related data.
ii) Other biological databases.
iii) Systems Biology, Synthetic biology and Simulations.
iv) Knowledge validation and building strategies in an infodense world.

While generally the whole organism, the cell or the molecule is considered the ultimate, authentic reference for biological study, we argue here that biological data such as sequences should now often be considered the most authentic data available; Indeed it is that on which much crucial knowledge in biology is built. While DNA maintains its central position, it most often now refers to immaterial sequences in a database –the information they carry rather than the molecules themselves. Of course sequencers rely on chemical analysis, and other apparatus for digitizing biological data rely on chemical or physical properties of biological structures, but data acquisition is ever more automated, and the new knowledge recognized by scientists and published in scientific journals stems more and more from the processing of this data, redefining what publishing means (NRC, 2003); An ever-increasing flow of information, both in science literature and in the media is the result and we argue that IT-based strategies are needed to validate and build scientific knowledge without getting overwhelmed(Marlene Scardamalia & Bereiter, 1996).

This redefines what authentic experimenting and biology doing is for reference biologist and thus shift what counts as authentic science education.

1. New opportunities for authentic biology in class ?

Since scientific research is the reference of authenticity in biology education we need to discuss how and where to transpose this change of what biologist effectively do.

1.5. Authentic tools to experiment and prove evolution

Genomic data, tools for comparing and extracting evolution evidence in conserved patterns, or building phylogenetic trees can be easily and freely accessed via Internet. Ever more research in evolution is based on sequence analysis, providing new and very strong evidence. These authentic data and tools, open new educational opportunities to explore, test and validate hypotheses. Possibly the strongest evidence ever is directly available to all schools. As part of a comprehensive teacher training program in Geneva, evolution teaching and inquiry modules were developed since 5 years with scenario-based modules freely available online. This has been discussed in more details elsewhere (Lombard & Blatter, 2009), so we will briefly refer to the conclusions, offer the website link to the scenarios (http://doiop.com/bist).
We believe the time is ripe for integrating IT-rich evolution into classrooms, but that this needs proper teacher training. We suggest explicitly addressing the fact that biology is changing, in particular by having recognized biology researchers describe how IT plays into their work. We suggest that teacher training designs needs inputs from i) disciplinary biology experts, ii) education experts and iii) linking disciplinary research and educational research to help teachers develop their expertise in pedagogical content knowledge (PCK) (Shulman, 1986) by focusing on scenarios.
We suggest this includes helping teachers develop information literacy strategies to avoid information overload, and should be thought of as a long-term training effort.
The design rules we proposed include the following: approach IT-rich biology as experimental lab work, empower students to use authentic data and tools whenever possible, design very precisely the technical part and loosely suggest the pedagogical part of scenarios. The opportunity of these new tools and data to reveal the underlying evolutionary basis of all of biology might be developed.

1.6. Authentic science validation by students ?

Educational technology has brought a new twist to the debate by offering opportunities to create environments supporting educational activities. Many contend that these activities can be authentic in terms of the mental processes even if the environment is virtual (Jonassen, 2003). The reference is here to authentic science as a process of validating knowledge.
Some authors insist the goal of education should be the production of knowledge, not only its re-production (M. Scardamalia & Bereiter, 2006). Conceptual artefacts (Bereiter, 2002) can be effective cognitive tools to support knowledge building and guide students into scientific building of knowledge.
New opportunities of validating knowledge by information processing are available for schools too: freely available articles (PubMed) and textbooks (Bookshelf) allow the new learning designs to learn, explore, confront ideas, test and validate hypotheses and to engage students in some of the cognitive processes of scientists. Some may recoil at this, but we feel these “new experiments” have essentially the same learning potential for science as hands-on laboratory: they can foster building of scientific knowledge

2. Research questions

We designed learning environments attempting to develop scientifically based knowledge.
Our research's general aim is to develop teaching models for IT-enhanced biology. It relies on the incremental refinement of learning designs within a Design Based Research framework (Design Based Research Collective, 2003). The outcomes are design features; they do not attempt comparison with a reference design as in the classical experimental paradigm.
Here we will discuss how design features related to this new authenticity enhance scientific knowledge building. We will in particular look for evidence that students are involved in the scientific process of establishing the source and certainty of knowledge, and the features of the design that might enhance or inhibit this development.
In this article we will discuss i) how confronting students with resources of varying degrees of authenticity influences scientific knowledge building, ii) which design features of IT supported iterative writing encourage authentic scientific validation of knowledge, iii) which design features develop autonomy in finding information in infodense environments. iv) what influence the status of the documents the students produce has on their involvement.

3. Methods

Data was collected from Wiki history (automatic records of all versions of the text) has data from refining the design over seven years in a Wiki-supported Inquiry (IBL Workshop Collective, 2001). Wiki history was analyzed for progress of writing one theme: "stratigraphic" analysis. Successive Wiki documents allowed yearlong analysis. Design iterations (2002-2009) allowed longitudinal analysis. Surveys, and follow-ups at university were administered. Some text was rated for epistemic complexity after Hakkarainen's four-point scale (Unelaborated facts, Elaborated facts, Unelaborated explanations, Elaborated explanations) (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007) and resource category use.
As the teacher and the researcher involved are the same, very radical designs could be explored, but introduced a strong bias. The results are based on data from seven years, the number of students each year was about 15. The conclusions are therefore exploratory and their generalizability has to be carefully evaluated. However we must remember that design rules are the results of this research not the comparison of this design with some reference design.

4. Basic design

This article refers to designs in high school, vocational and continued training. The most well-documented design (Inquiry Based Learning "IBL" hereafter), was implemented for most of each year with 19 year old high-school students majoring in biology addressing molecular biology, immunology and evolution. The learning design was scaffolded by a wiki aimed at developing authentic science knowledge building strategies. Critical features of the design are searching, selecting, and discussing resources of various degrees of authenticity, as well as highly iterative co-writing (5-10 revisions over the course of 3-4 weeks) in the Wiki – the conceptual artifact– and repeated presentation of knowledge in construction. Each group of students were "experts" in a sub-theme, wrote for their peers, and the responsibility of producing helpful texts for preparing exams provided an authentic audience.

5. Selected results

First a few general results for context: The IBL design got basic validation in 2002 – repeatedly confirmed since – that it allows students to produce texts demonstrating sound in-depth

biological knowledge. Although Geneva has no standardized exams, anecdotal evidence suggests student results were as good as other classes or better. Follow-ups one year after –at university (mostly medicine) – indicated they felt having acquired efficient learning strategies, and good basic knowledge.
The first iterations established that control by the teacher of the questions addressed can ensure curriculum coverage, and that student ownership of questions is crucial and is feasible but implies separating the curricular responsibility of the teacher from the scientific validation role. The design was formally conceptualized as IBL in 2003.
Further iterations revealed the importance of focusing students on a meaningful production ("Matrioshka" model, (Lombard, 2007)), and a clear, shared understanding of this document's status. Here, it was framed as an exam-preparing brochure.
The writing to learn features were then explored, highlighting the importance of an authentic audience for which to write.

5.1. Feed-back and teacher stance

The tone of the feed-back appeared in the first iterations of the design as critical: "an error-hunting teacher as the sole audience, may do little for the writer, whereas a topic the writer cares about and an audience responsive to what the writer has to say are the essential ingredients for a profitable experience." (Bereiter & Scardamalia, 1987). Teacher feed-backs that respects student ownership of text, suggests modifications, refers to sources for development, rather than directly correcting appeared as very important, as rewriting by the teacher might lead to disengagement of students. It is worth noting that this implies imperfect text will remain in the final document. The teacher's tolerance of imperfection being seen under his responsibility is also an issue (Horman, 2005), which highlights the importance of clear, visible ownership of the text by students and common understanding of status of the document as a help for exams.
We suggest that to allow science doing, the teacher relinquish content ownership of text to students, and tolerate imperfection, but assert teacher authority on workflow and curriculum through the control of questions, very explicit assignments, and criteria for scientific validation and structure of text. Give students a lot of freedom for finding and writing content but within a strong framework defining knowledge justification quality and structure of the document produced. Be prepared for feed-back, feed-back, *ad nauseam.*
Consequently, one might need to create opportunity to establish scientific authority of teacher as the design puts him out of the knowledge transmitting role.

5.2. The importance of knowledge confrontation

In the most recent iterations of the design attention was focused on the opportunities and quality of idea confrontation by the students. Indeed confrontation of ideas and reviewing is an essential part of the scientific process of validation.
Educational research highlights the importance of epistemic confrontation, in socio-cognitive conflicts rather than relational conflicts (Buchs, Butera, Mugny, & Darnon, 2004).
Attempts were made at driving to adequate content by knowledge confrontation not authority and to create opportunity for students to discuss partly elaborated ideas. The texts were discussed in front of all, and co-writing was intended to encourage epistemic confrontation, we could explore to which degree the writing process engaged students in the same knowledge-building confrontations as scientists. It appears, the students limited confrontation opportunities by

adopting strategies to separate the common text into blocs they managed individually. Modification of the design (each student in turn was “editor” and had the role of insuring coherence of the texts) produced limited results, as it clashed with last-minute working habits, and stretched the limits of student involvement further than what they could accept.
We believe this is an important aspect to design for and would consider design features such as intergroup activity (Meirieu, 1989).

5.3. A few results discussed in relation to authenticity

The yearlong analysis shows many signs of greater in-depth involvement – for example a clear increase in epistemic complexity of texts produced during the course of six months On a typical wiki page in its final version the number of facts stated increased moderately, and the number of unelaborated explanations increased from 11 to 55, and the elaborated explanations from 3 to 16. (See figure 1).

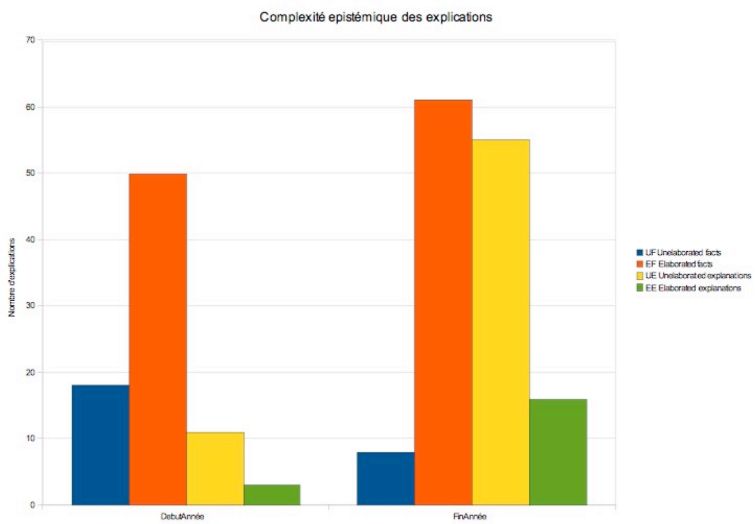

Figure 1: Epistemic complexity of ideas : Number of occurrences for each category on Hakkarainen's four-point scale over the course of ~6 months for one typical wiki student production.

5.4. Strategies for selecting resources of varying authenticity

The design offered students a rich choice of resources, they were free to choose. The quality of answers was assessed, and feed-back was provided, often with reference to on-line resources. In-class resources included a selection of textbooks, a few academic textbooks (Parham, 2002) and access to academic on-line textbooks in English (Janeway, Travers, Walport, & Shlomchik, 2001). A large part of the student work was done from home and most students relied heavily on internet resources and a textbook (Raven, Johnson, Losos, & Singer, 2007).
Observation in class by teacher and other observers revealed during the year a shift towards resources of increasing authenticity, occasionally even referring to primary literature.
For example one wiki page about humoral immunity contains 10 explicit references and 7 figures from Janeway on-line.
In the questionnaire, students gave selective preferences about sources they would choose for precise questions with their textbook being the most often referred to (μ=3.1 on a scale form 1 to 4) and Wikipedia much less often. Together with their comments suggests that students have developed strategies for selecting different sources depending on the type of question. They knew

more than Wikipedia and choose textbooks or academic books for elaborate questions, and mastered strategies for searching. Many students mentioned that they went for thick books as where they had more chances of finding, whereas big books had been frightening.
Appropriate questions not only direct student activity, but allow discarding irrelevant information, moving students from an exhaustive view of learning to data-mining strategies.
Globally they declared feeling empowered to learn in a world of information overload (μ=3.05 on a scale of 1 to 4).

5.5. Autonomy in finding information

Most (72%) declared they felt the balance between scaffolding and autonomy adequate (3 or 4 on a scale of 4) at the end of the year. They nearly all (93%) declared appreciating the freedom (3 or 4 on a scale of 4) while many mentioned this design demands much more work.
Students demonstrated increasing autonomy in finding explanations themselves, the main evidence being the wiki pages that contain quality information that the teacher didn't provide.

5.6. Self validation of knowledge : authentic science doing ?

Analysis of the answers to the questionnaire suggested that tolerance of uncertainty might be a key factor. Students differed greatly about how they felt with the responsibility of validating knowledge themselves: asked about the fact the teacher doesn't give the answers, on average they answered quite positively (μ= 3.0 out of 4), but variance (σ = 1.04) was great. Interestingly answers to this question correlate strongly (0.64**) with feeling that they developed knowledge extraction capacities and also (0.56**) with seeing the wiki as a good support for structuring ideas. It didn't correlate well with exam results (negative, non significant), and was stable during the year.
More than half of the students felt positively about having to find answers themselves. Asked about fear that some information found might be wrong, they answered –at the end of year– that is wasn't any more a problem, referring to checking sources, logical coherence, or the fact there is no final truth in science.
Together these results suggest that most pupils were at ease developing their own validation of knowledge but that a few felt uneasy without teacher validation. The effects of this discomfort and uncertainty of some students on their investment remains unclear, and might be related to personal and cultural views about challenging authority.
However these results provide reasonable evidence that students are tagging their knowledge with some of the metacognitive attributes: certainty, source and structure. They appear to be building partly scientific knowledge in the sense we defined here.
We suppose that working with peer-created documents of doubtful quality might have helped: knowing what they read might be partially wrong requires a constant validation of information leading to developing the attribute of uncertainty and source.
This suggests a design feature : that students –once equipped with data-mining and text-organizing strategies – should be repeatedly confronted with a wide array of documents to give opportunity for validating information. This also suggests including documents of uncertain quality as well as high quality authentic references so that their difference can be experienced. As it happens the former is just what internet provides, whereas the latter needs help.
It is also worth noting that validating information from a soup of overabundant information is an authentic skill that is of great importance for any citizen.

5.7. Are we sure they learn the right stuff ?

One issue that teachers often are concerned about is that students might learn errors if the documents they are provided are imperfect. Also there is a tension between developing a scientific way of validating knowledge by students and striving to an acceptable understanding of content (William A. Sandoval & Daniszewski, 2004). However, the quality of the document produced must not be confused with the learning it supports; imperfect documents have been shown here to support good learning.

Our designs suggest that when students are engaged by well-chosen questions, if adequate resources are available, and with some tutoring good answers can be found, and decent quality text produced. When students used these documents – which they know are imperfect– to learn, they were constantly assessing certainty, justification of the information; practicing some of the cognitive skills that characterize science.

Also repeated presentation to peers provides good feed-back about the quality of the knowledge students are developing, making them aware where understanding is insufficient (the certainty attribute), which leads to more searching, rewriting and finally better knowledge. Presentation also allows refocusing and ensures the learning process covers the curriculum.

5.8. Trust in the Learning design

We ponder that trust in the learning potential of the design must be established for students to get students involved particularly high performers. A design feature would be : create opportunity to establish learning potential of the design.

might be more difficult to obtain by inexperienced teachers. The type of resources used here were found efficient for these particular students and might not be adequate for others. We do not suggest attempting to generalize this design, Rather, we propose that the design rules could be used to create other designs.

6. Conclusions

To conclude we propose that science teaching might be focused on developing scientific knowledge with reference to certainty, justification, structure and source.

We also argue that new biology offers a vast array of authentic data and tools that can be harnessed to develop these attributes of knowledge in designing biology teaching. They are authentic sequences and biological data, authentic tools for processing data, but also authentic literature and IT-supported authentic science validation learning environments.

In particular we suggest students not be protected from, but confronted to abundant resources of varying authenticity in guided inquiry. Documents of uncertain value should be available, but the students must engage repeatedly in scientifically validating of the knowledge produced. Meaningful documents can help students to process information into their own scientific knowledge. This is the authentic science process.

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