2 NEW OPPORTUNITIES FOR AUTHENTICITY IN A WORLD OF CHANGING BIOLOGY

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Abstract

Biology now produces massive data, genomic and other types. New ways of building knowledge are thus increasingly reliant on data processing. Biological data and analytical tools, widely accessible via the internet, offer new authentic opportunities to explore, test and validate hypotheses in numerous fields of biology and allow students to engage in the same cognitive processes associated with hands-on biology. New authentic text resources are also freely available, enabling students to practice the authentic scientific process of knowledge validation. Indeed science is a process of building knowledge by confronting ideas, and discussing their certainty, the links to the data that they are built on and their source. Framing authenticity in terms of resources and student activities, we have spent 7 years refining designs for building scientific knowledge within wiki-supported learning environments that confront students with an overabundance of resources of differing authenticity.

We will discuss the influence of resource authenticity, and of the students being progressively given responsibility for validation, on the development of scientific knowledge and learning strategies. Results include an increase in the epistemic complexity of student-produced texts, a shift towards using increasingly authentic resources, and autonomy in validating information. Some authenticity-linked design features, and generalisability, will be discussed.

Keywords: knowledge building; didactics; design; inquiry; authenticity

1. Introduction

The importance of authenticity in education has long been recognized (Dewey, 1911; Freinet, 1960), but is intrinsically limited by didactic transposition (Chevallard, 1991). Our goal was to develop and analyse designs that would involve students in the authentic scientific process of validating their own knowledge.

1.1 Authentic science?

In its most general sense, “authenticity” represents the search for some similarity between educational processes and those practiced by “real people”. In general, “doing biology” implicitly refers to scientists and their activities, questions and methods: the “social practice

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of reference" (Martinand, 1989). Here we discuss authenticity in terms of the resources or tools provided and authenticity of the learner's processes, activities and productions.

We identify three authenticity levels, modified from The Cognition and Technology Group at Vanderbilt (1990): (1) true research data, considered more authentic than carefully selected, educationally polished data; (2) tools and methods: involving students in similar tasks, with the same tools and methods used by professionals; (3) "doing real research": creating new—or at least locally new—scientific knowledge. "Doing science" in education should help students build the scientific properties of their own knowledge, rather than simply learning facts. The way in which knowledge is validated is one key attribute that will be discussed in this article.

Here we define science as a method for validating knowledge (Sandoval & Morrison, 2000) based on confrontation with data and alternative explanations. Indeed the process of science relies on argumentation and debate to validate knowledge, although these are virtually absent from science education (Osborne, 2010).

The classification of knowledge as scientific does not depend on its subject (about animals, ecosystems or sequences) so much as on its being grounded in sources, in the data on which it is based, and in its justification leading to a given 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 knowledge when it is based on i) the source of this figure (The Chimpanzee Sequencing and Analysis Consortium, 2005), ii) the justification by methods used (differences in terms of nucleotide substitutions), iii) the links to the data (full genome accessible in MapViewer), iv) the comparison with other methods for establishing similarities (DNA hybridization, gene homology, SNP identity, sequence identity, etc.). A person who "knows scientifically" can infer from this structure, guarantee 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*, a textbook or the teacher). When a student states "1.23%", one cannot distinguish scientific from naive knowledge.

One major difficulty of getting students to "know scientifically" is the tension between developing a scientific way of validating their knowledge and striving for an acceptable understanding of content (Sandoval & Daniszewski, 2004). The issue revolves crucially around validation: if the authority for validation lies with the teacher, students will have little incentive to engage in that demanding scientific process. Striving to place the authority for validation in the most authentic experimental data and literature possible for the students and the teacher in a guiding role is a key issue of this research. Hence the focus is on available resources and validation processes.

1.2 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, 2010)—and have shown important effects on motivation and learning outcomes. Even the use of slightly more authentic resources can have educational effects.

We graded the authenticity of resources from school books, popular magazines, and primary literature. Sequences accessible through web portals such as UniProt or Mapviewer, and online books from the NIH database bookshelf are considered more authentic than the same data illustrated in school textbooks.

1.3 Can changing biology's authentic tools engage students in scientific validation of their knowledge?

Biology is deeply changing under the influence of information technology (IT) (NRC, 2003; Pevzner & Shamir, 2009): massive amounts of new data (genomic, botanical, biogeographical, etc.) are available, new tools are being offered (sequence searching and comparisons, phylogenetic tools, etc.), and most scientists spend a large part of their time building biological knowledge by practicing "*in silico biology*".

In fact, data processing alone often qualifies as research in high-impact journals. For example, comparing the human and chimpanzee genomes for evidence of recent change (Pollard et al., 2006) is a legitimate contribution to biological knowledge, even though results were obtained by IT alone, based on freely available genomic data produced by others.

While the whole organism, the cell or the molecule are generally considered the ultimate, authentic reference for biological study, we argue here that biological data such as sequences are often the most authentic data available in schools. This new way of creating knowledge using data from public databases, represents a considerable change in the reference activity of "doing biology". It has been widely adopted by researchers (Strasser, 2006), but appears to have been mostly ignored by education (Lombard, 2007).

Since scientific research is the reference for authenticity in biology education, the fact that it is changing implies that we need to be discussing if and how science teaching should change as well. Elsewhere (Lombard & Blatter, 2009), we discussed a comprehensive teacher-training program in Geneva, for evolution teaching and inquiry in evolution, based on sequence analysis. However, the possibilities for authentic science education are not restricted to the use of scientific data. They include all forms of scientific knowledge contained in scientific publications. Biologists not only analyze data, they also critically discuss the content of scientific publications. Indeed, confrontation of ideas and review are essential parts of the scientific process of validation. Thanks to the development of bibliographic search engines (PubMed), online journals or academic books (NIH_Bookshelf), and open-access policies, students and teachers can now engage in the classroom in the same kind of critical discussions performed by researchers in the laboratory. New learning designs can use these to foster learning, exploring, confronting ideas, testing and validating hypotheses and engage students in some of the cognitive processes of scientists.

Educational technology has added 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).

Some authors insist that the goal of education should be the production of knowledge, not only its reproduction (Scardamalia & Bereiter, 2006). Conceptual artefacts (Bereiter, 2002) can be effective cognitive tools to support knowledge building and guide students into the scientific building of knowledge.

Research (Britton, 1972; Vygotsky, 1978) supports the idea that writing is not only a medium for communicating pre-existing ideas, it also supports the development of ideas (Keys, 1999).This is in contrast to common practice where writing is mainly used to assess a student's current understanding or as evidence of completion of an activity. When writing is used, it is not often explicitly managed as a process for building knowledge.

Our approach is inspired by Bereiter and Scardamalia (1987). Co-writing in a shared writing space such as wikis can create opportunities for scientific validation via the confrontation of ideas. Numerous writing iterations and feedback tone are 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). In addition, educational research highlights the importance of epistemic confrontation in socio-cognitive rather than relational conflicts (Buchs, Butera, Mugny, & Darnon, 2004).

2. Research questions

The general aim of our research is to develop and evaluate learning environments for IT-enhanced biology. This relies on the incremental refinement of learning designs within a design-based research framework (Design Based Research Collective, 2003). The outcomes are therefore links between design features and educational outcomes, rather than a comparison of a given design with a reference as in the classical experimental paradigm.

In this study, we focus on the effects of authenticity of resources and authenticity of the process of scientific validation on the development of scientific knowledge and learning strategies. In particular, we looked for evidence of students being involved in the scientific process of establishing the source and certainty of knowledge, and determined the design features that enhance this development.

Specifically, we discuss i) how confronting students with resources of varying degrees of authenticity influences scientific knowledge building, ii) which design features of wiki-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 produced by the students has on their involvement.

3. Methods

This study was conducted between 2002 and 2009, with seven different classes totalling 83 students, over the course of one full academic year. Nineteen-year-old secondary school students majoring in biology were arbitrarily assigned to these classes. The study covered 100 hours in class, and the curriculum covered molecular biology, immunology and evolution.

The learning design was scaffolded by a wiki in which students wrote their progressive understanding of scientific questions on one sub-theme of a chapter in inquiry cycles lasting 3 to 4 weeks, after which the class addressed a new chapter.

Data were collected from the wiki's history (automatic records of all versions of the text) over 7 years. They were analyzed for progress in writing one theme: “stratigraphic” analysis. Successive wiki documents allowed year-long analysis. Design iterations (2002-2009) allowed longitudinal analysis.

A selection of text was rated for epistemic complexity using a four-point scale adapted from Zhang, Scardamalia, Lamon, Messina and Reeve (2007): each logical text unit was placed into one of four categories: unelaborated facts, elaborated facts, unelaborated explanations, elaborated explanations.
Resource category used was determined by references in the student’s text, or by comparing

the text with the sources known to be used by students. Coding was done only by the researcher, and interceding is currently being established.

Questionnaires were administered at the beginning and end of each year: they investigated (using Likert scales or a short text) representations of science, resource selection and learning strategies, feelings of autonomy and support, preferences about the efficiency of group work (50 questions). The results refer to the last year and the final design. Shorter follow-ups were administered by e-mail one year later when the students were at university to explore perceptions of the adequacy of the learning and strategies for academic study.

Descriptive analysis was applied, correlations were sought. Text answers were coded and common answers extracted. Triangulation of data was performed.

As the involved teacher and researcher were one and the same, very radical designs could be explored, but even though the data cover a long period and many iterations of the design offer a good foundation for discussion, conclusions must be seen as exploratory and generalisability of the established design rules has to be carefully evaluated.

4. Basic design

Since in the design-based research paradigm, the design is iteratively refined, its main features are both the results, and the context in which they were elaborated. Here we present the latter.

Each group of students was responsible for a sub-theme, and wrote texts for their peers framed as the main preparation for important exams, in lieu of lectures. The students went through a cyclic succession of activities running 3 to 4 weeks: eliciting questions, gathering preliminary explanations and facts, performing a primary search, deepening the search, co-writing in the wiki, giving an early presentation to peers of the concurrent understanding of questions and answers, refining the questions, deepening the search, restructuring the text, giving a final presentation to peers, performing a final revision of the text, and sharing the exam-preparation brochure. Highly iterative collaborative writing (5-10 revisions per cycle) and repeated presentation of knowledge in construction engaged the students in the authentic process of validating.

A key structuring feature was the requirement that all paragraphs answer an explicit question in their title. This ensured focusing on a single concept, and allowed effective control by the teacher on the direction of the inquiry while leaving the responsibility of finding answers and integrating them into a coherent text with the students. The decision of where to search for the answers was left to the students, but when asked for help or when errors were found, the teacher did not correct the student text, but rather offered links to some of the newer authentic data, tools and experiments where better answers could be found. As students became more knowledgeable, resources of high authenticity were needed and students were not restricted to the usual textbooks, but were encouraged to use academic books for specific questions.

The first iteration (2002) validated the design, proving that it could lead students to appropriate knowledge and success in final exams. Changes in the design were introduced over the years: the 2003 iteration linked the structuring of the inquiry with the guidance and subject’s in-depth coverage around the rule that each paragraph should answer one question, and that questions are negotiated; this was formally conceptualized as Inquiry Based Learning (IBL Workshop Collective, 2001). The 2004 iteration introduced oral presentations to peers. The 2005 iteration changed perspective, integrating the teacher as a dependent variable that changes under the influence of the design and adding access to academic textbooks. The 2006 iteration refined the writing to learn features, e.g. introducing editor roles for students. The 2008 iteration introduced cooperative learning features such as authoring records, texts discussed in front of peers early in the learning cycle, creating opportunities for students to discuss partly elaborated ideas and co-writing, organized to encourage confrontation in socio-cognitive conflicts.

5. Selected results and discussion

After giving a few general results, we present a selection of results related to authenticity and scientific knowledge. Each result is immediately discussed.

The design received basic validation in 2002—which has since been repeatedly confirmed—in that it allowed students to produce texts demonstrating sound in-depth biological knowledge. Although Geneva has no standardized exams, convergent anecdotal evidence suggests that student results were as good as, or better than those in other classes. Follow-ups one year later—at university (mostly in medicine)—indicated that the students felt they had acquired efficient learning strategies, and good basic knowledge.

The first iterations established that teacher control of the addressed questions could ensure curriculum coverage, and that student ownership of the questions is crucial and feasible but implies separating the teacher's curricular responsibility from his/her scientific validation role. Further iterations revealed the importance of focusing students on meaningful production (*Matrioshka* model, Lombard, 2007), and on a clear, shared understanding of the document’s status. Here, it was framed as a shared exam-preparation brochure.

The frequency and tone of the feedback appeared as critical in the first iterations of the design. Teacher feedback that respects student ownership of the text, suggests modifications and refers to sources for development, rather than involving direct corrections, emerged as decisive in allowing students to experience the process of validation. Furthermore, too much rewriting by the teacher might lead to the student’s disengagement. However, this implies that an imperfect text will remain in the final document. The teacher’s tolerance of an imperfect text which is seen to be his/her responsibility is also an issue (Horman, 2005), which highlights the importance of clear, visible ownership of the text by students and a common understanding of the status of the document as help for exams.

Our results suggest that to allow the performance of science, the teacher can relinquish text-content ownership to the students, and tolerate minor imperfections, but needs to assert teacher authority on work flow and curriculum through the control of questions, very explicit assignments, and criteria for scientific validation and structuring of the text. Defining a clear framework for the writing assignments left the students with a lot of freedom in finding and selecting content.

As the design removes the teacher from the knowledge-transmission role, one might need to create an opportunity for the teacher to establish scientific authority early in the year.

Analysis of the writing process for knowledge confrontation showed little trace of socio-cognitive conflict. The presentations encouraged confrontation, but little discussion was observed. What might have happened orally outside of class is not available. Altogether, it appears that the students limited confrontation opportunities by adopting strategies to separate the common text into blocks which they managed individually. Modification of the design (each student in turn was “editor” and had the role of ensuring coherence of the texts) produced limited results, as it clashed with last-minute work habits, and possibly stretched the limits of student involvement further than what they could accept. Nevertheless, we believe that this is an important aspect to design for and would consider incorporating design features such as intergroup activities (Meirieu, 1989).

The year-long analysis shows many signs of greater in-depth involvement in knowledge structure—for example a clear increase in epistemic complexity of the texts produced over the course of 6 months. On a typical wiki page, in its final version, the number of facts (elaborated or unelaborated) changed only moderately, but the number of explanations increased greatly (Figure 1).

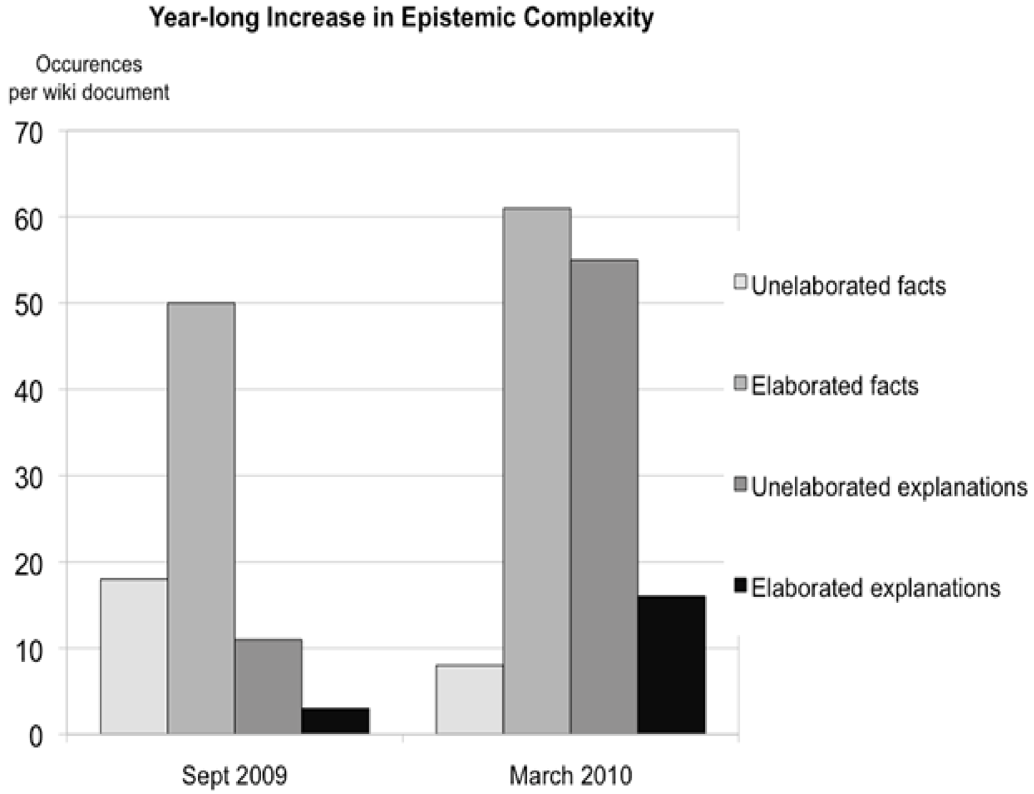

Figure 1. Beginning-end comparison of epistemic complexity, measured as number of occurrences for each category in one typical wiki student group production. See methods for details.

Self-validation of knowledge

The design offered students a rich choice of resources from which to choose. The quality of the answers was assessed and feedback was provided, often by referencing on-line resources. In-class resources included a selection of textbooks, a few academic textbooks such as Parham (2002), and access to academic on-line textbooks in English such as Janeway, Travers, Walport and Shlomchik's (2001) on-line version. A large part of the student's 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 a teacher and other observers over the course of the year revealed a shift towards resources of increasing authenticity, occasionally even referring to primary literature. For example, one wiki document produced at the end of the year, on humoral immunity, contained 10 explicit references and 7 figures from Janeway on-line.

In the questionnaire, students ranked the sources they would choose for precise questions according to preference, with their textbook being referred to most often ($\mu=3.1$ on a scale from 1 to 4) and Wikipedia much less often. Their comments also suggested that the students had developed strategies for selecting different sources depending on the type of question. They knew more than Wikipedia and chose textbooks or academic books for elaborate questions, and mastered strategies for searching. Many students mentioned that thick books had been daunting, but they now preferred them since they are more likely to contain relevant answers.

Appropriate questions not only directed student activity, but also allowed discarding irrelevant information, moving students from an exhaustive view of learning teacher-selected documents to data-mining strategies.

Overall, the students declared feeling empowered to learn in a world of information overload ($\mu=3.05$ on a scale of 1 to 4). Most (72%) felt that the balance between scaffolding and autonomy was adequate (3 or 4 on a scale of 1 to 4) at the end of the year. They nearly all (93%) declared appreciating the freedom (3 or 4 on a scale of 1 to 4), while many mentioned that this design demands much more work. Students demonstrated increasing autonomy in finding explanations themselves, as attested by wiki documents that contained quality information that the teacher had not provided.

Analysis of the answers to the questionnaire suggested that tolerance of uncertainty might be a key factor. Students differed greatly in terms of how they felt with the responsibility of validating knowledge themselves: asked about the fact that the teacher does not give the answers, on average they answered quite positively ($\mu=3.0$ out of 4), but variance ($\sigma=1.04$) was high. Interestingly, answers to this question correlated strongly (0.64**) with feeling that they had developed knowledge-extraction capacities and also (0.56**) with seeing the wiki as a good support for structuring ideas. They did not correlate well with exam results (negative, non-significant), and were stable throughout the year. More than half of the students felt positively about having to find answers themselves. Asked about the fear that some of the found information might be wrong, they answered—at the end of the year—that this was no longer a problem, referring to checking sources, logical coherence, or the fact there is no single 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 in some students on their investment remain unclear, but might be related to personal and cultural views about challenging authority. However, these results provide reasonable evidence that students are tagging their knowledge with certainty, source and structure, metacognitive attributes. They appear to be building partly scientific knowledge in the sense defined herein.

We assume that working with peer-created documents of doubtful quality might have helped: knowing that what they are reading 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 documents as the main authority for validating their knowledge. It also suggests including a wide array of documents of uncertain quality as well as high-quality authentic references, so that their differences can be experienced. As it happens, the former is just what the internet provides, whereas the latter needs guidance. It is also worth noting that validating information from a swamp of information is an authentic skill that is of great importance for all of today's citizens.

The tension between students validating scientifically and striving for acceptable content rendition remains an issue for some teachers who worry that students might learn errors if the documents they are provided with are imperfect. We must, however, not confuse the quality of the produced document with the learning it supports. This research strongly suggests that imperfect documents can support good learning once students possess good validation strategies, and the design includes features to guide the inquiry: presentation to peers provides decisive feedback on the quality of the knowledge the students are developing, making them aware of where understanding is insufficient, which leads to more searching, rewriting and ultimately, better knowledge.

Results suggest that trust in the learning potential of the design must be established for students, especially high performers, to get involved. It might be critical to create an opportunity to establish the learning potential of the design, such as testimony from students at university.

6. Conclusions

To conclude, we propose that science teaching focus on helping students develop scientific knowledge referenced to certainty, justification, structure and source. We also argue that the new biology offers a vast array of authentic data and tools that can be harnessed to develop these attributes of knowledge in the design of biology teaching. These 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 that students not be protected from, but rather be confronted with abundant resources of varying authenticity in guided inquiry. Documents of uncertain value should be available, but the students must engage repeatedly in scientific validation of the knowledge produced. Meaningful documents can help students process information into their own scientific knowledge. This is the authentic science process.

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