Visualising the science of genomics: cognitive and social interactions that promote learning in an online collaborative research project

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Abstract: *Visualising the Science of Genomics (VSG) is an open inquiry-based approach to enable students to experience the thrill of collaborative scientific research in the field of genomics. The primary goal of VSG was to engage students in the dynamic process of scientific inquiry using a multidisciplinary approach in an online environment. Students worked in teams to analyse, hypothesise, reflect, predict, and formulate models based on genomic sequence data from the Human Immunodeficiency Virus-1 (HIV-1), the causative agent of AIDS. Contextual relevance was provided through the creation of case studies based on actual data. The goal of VSG was to allow students to assess and interpret available information, and to develop their own research questions and methodology. VSG emphasised the process of investigation, facilitating students' metacognitive awareness of the scientific approach. The VSG project provided not only an inquiry-based approach to facilitate open-ended research, but developed a sense of ownership in students and resulted in the creation of a global online research community through multidisciplinary collaboration.*

Introduction

The international research project Visualising the Science of Genomics (VSG) engages students in the active process of collaborative scientific inquiry. The project was conducted entirely online amongst geographically distanced participants who worked in 'research teams' of five students, each from a different country. The project was trialled for a two-week pilot to investigate the pedagogical potential of a fully online research community. Participants represented a diversity of scientific backgrounds including: microbiology; bioinformatics; medicine; chemical engineering; biotechnology; pharmaceutical sciences; molecular biology; medical chemistry; genetics; biochemistry; mathematics; and computer science. The international and multidisciplinary composition of each research team provided the context for scientific research as a concerted global effort dependent upon contributions by scientists with specific areas of expertise.

The VSG approach aims to break from the traditional university laboratory practical, which, in dictating the 'aim of the experiment' and the predetermined methodology, omits a significant aspect of the student learning experience. In principle, the laboratory introduces the student to the practice of biology, whereby the learner is provided with the opportunity to apply his/her theoretical knowledge. One of the goals of the biology educator is to teach students how to 'think like scientists'; we aim to engage the student in a cognitive apprenticeship as a researcher. Paradoxically, in most laboratory courses the laboratory manual specifies the 'aims' or 'hypotheses', and the student follows an established protocol to conduct the experiment. A true cognitive apprenticeship, however, must include development of the thought processes that facilitate the formulation of a hypothesis, as well as the reasoning processes invoked in the development or application of appropriate methodology to test the hypothesis. Hence whilst technically the laboratory provides a tangible context, focus on content and outcome may override learning how. The VSG project endeavoured to foster authentic inquiry through the creation of a research community whereby knowledge was synthesised through collaborative investigation.

In view of the diverse backgrounds of the participants, preliminary information was sent to all participants prior to the start of the project. The information included background reading on HIV-1 as well as a CD-ROM tour and necessary technical information for the online work. The students were also encouraged to post brief introductions about themselves in their team sites to initiate students into the social framework of their learning community. The VSG student community was exceptionally diverse, consisting of students from different scientific majors, levels of study, and cultural and ethnic backgrounds. The international and multidisciplinary composition of each research team was reflective of how scientific research is indeed a concerted global effort dependent upon contributions from partners with specific areas of expertise.

After receiving their individual case studies, the teams faced the challenge of developing their own research question(s) and appropriate methodology for investigation. Unlike most courses encountered in their academic careers, instead of being prescribed an ‘aim’ and corresponding protocol for their experiment, the students’ initial (and most difficult) pursuit was ‘what is my question?’ Furthermore, the students were not constrained by the need to derive a ‘correct answer’, for the emphasis of VSG was on process via the open-ended learning experience, and not on results.

> Since we are given only the case studies, [they] provided us [with] a better opportunity to research into different aspects with the given data instead of madly following instructions from lecturers without understanding. The process of asking ‘why’ in the whole research project is important which usually disappears in the case if all of the instructions are given and [the] student is just a ‘follower’. *(student quote from feedback evaluation form)*

Despite the brief timeframe of the pilot study, a strong sense of community and ownership developed amongst the students as the temporal and geographical differences fostered a dependency on online collaboration. The intensity of this community and the bond developed between them and the instructor was surprisingly strong considering the groups were together as a community for only two weeks. The learning outcomes from this group of students were of an exceptionally high calibre.

Approach and Results

The cognitive/social interactions were assessed by examining the dialogic interactions in three areas (interfaces) of the VSG environment: Discussion and Feedback; (D and F); Chat; and Message Board). The schematic below (‘VSG online interaction’) represents the possible avenues of dialogic interaction amongst students, and between students and instructor (tutor) in the VSG community.

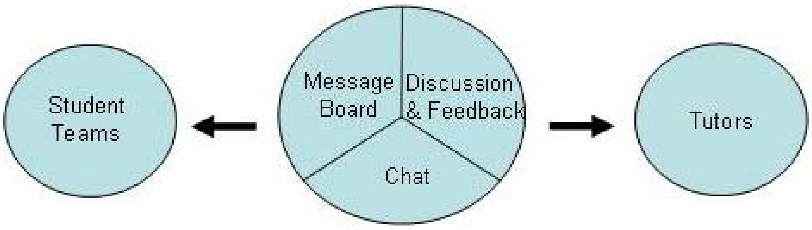

Figure 1. VSG Online interaction

Data were collected in the form of complete transcripts from each of these interfaces. Initial detailed cognitive assessment of student interactions in this community revealed that the social interactions were oft inherently linked to the synthesis and application of new knowledge. It became apparent that assessment of the interactions leading to the learning outcomes required integration of this observation into the methodology. Rubrics were therefore developed to categorise both the: a) social; and b) cognitive interactions that occur in VSG.

Analysis of social interactions in the VSG community

According to Shaffer and Anundsen (1993), ‘community’ is defined as a dynamic entity that emerges when a group of individuals share common practices, are interdependent, make decisions jointly, identify themselves with something larger than the sum of their individual relationships, and make a long-term commitment to well-being (their own, one another’s, and the group’s). The online community is dependent upon these same attributes in the absence of face-to-face contact or a voice. Indeed, the initial challenge of a project like VSG is the development of the community itself, as learning goals are concurrently being frameworked.

The rubric for assessing social interactions was developed based on Sringam and Geer's Cognitive Development Interactive Analysis Model (Sringam and Geer 2000), with the inclusion of an additional category, 'socialisation'. The seven categories in the modified Sringam and Geer rubric were as follows:

- socialisation;
- planning;
- sharing/comparing/contributing information;
- identifying or clarifying inconsistency of ideas, concepts or statements;
- negotiation of meaning/co-construction of knowledge;
- testing and modification of proposed synthesis or co-construction of knowledge; and
- agreement statement(s) and application of newly constructed knowledge.

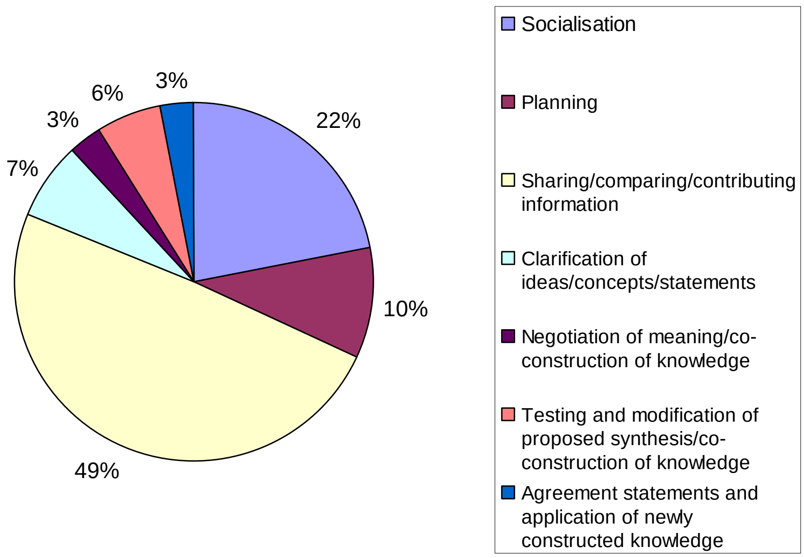

Figure 2: Categories of social interactions amongst students in VSG Discussion and Feedback

The two main categories of social interaction were: i) socialization; and ii) sharing, comparing and contribution of information. Whilst socialisation (22% of interactions) plays a significant role in facilitating collaborative learning, task-related interactions (78%) were predominant in the VSG community. This is indicative of student commitment and strong involvement in the investigation. Furthermore, a common observation amongst the groups was the negotiation and development of a shared understanding re: 'the problem' (task). While this sometimes took the majority of the students' time during the 2-week project, this process was in itself a conduit toward cognitive development. This is evidenced by the dialogic progression within a group that resulted in continual reflection and process-oriented critical analysis.

> Being able to direct our own investigation was a little unnerving at first (it is a learning style that I am not used to), but I came to realize that this learning technique gave me a sense of pride; I had ownership of my data. This sense of pride and ownership motivated me to work hard to understand the problem as much as I could in the time available. (*student quote from feedback evaluation form)*

The social interactions in the VSG community were integral to the collaborative learning efforts of its members. Palloff and Pratt (1999) stress the importance of the development of shared goals that are related to the learning process in an online community. The integration of these goals into the social dialogue amongst the VSG students was indeed reflective of this engagement.

> Collaboration is perfect when team members can almost read each others minds. I have experienced it before and I feel it takes a lot of communication and getting to know each other for team momentum to build up, but it's a wonderful thing when it does happen. (*student quote from feedback evaluation form)*

Analysis of cognitive interactions in the VSG community

One of the key criteria for an authentic learning experience is that of fidelity of context (Meyer 1992; Wiggins 1993; Reeves and Okey 1996; Herrington and Herrington 1998). For many of my students, it was the first time in their academic careers that they found themselves immersed in collaborative authentic inquiry, whereupon they were driven by intrinsic motivation.

> The freedom to take the investigation in any direction has been quite good, as it allowed flexibility *(student quote from feedback evaluation form)*

The rubric for assessing cognitive interactions was based on Biggs' and Collis' Structure of Observed Learning Outcomes (SOLO taxonomy) (Biggs and Collis 1982). The majority of the interactions as assessed via SOLO taxonomy were indicative of higher levels of cognitive ability (relational and extended abstract).

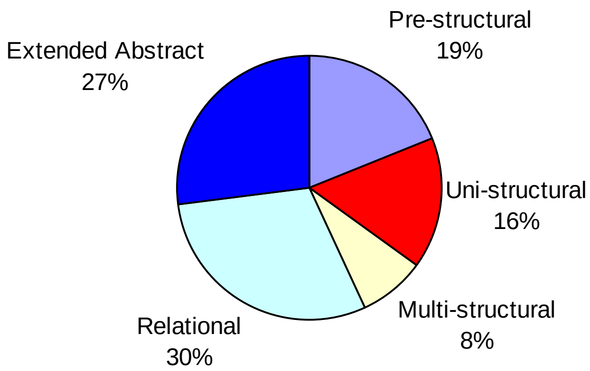

Figure 3. Cognitive assessment of student interactions in VSG Discussion and Feedback by SOLO taxonomy.

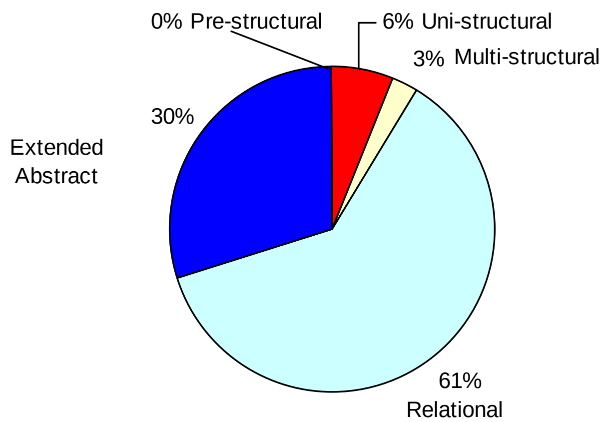

Figure 4. Cognitive assessment of student interactions in VSG Chat by SOLO taxonomy

Student discussions were characterised by analytical, contextual, and social dialogue. The instructor provided feedback and facilitation when appropriate. Whilst most teams initially performed similar preliminary 'experiments', the defined goals, specific datasets chosen, and strategies developed by the teams varied. This diversity of approaches exhibited by teams to develop their 'question' and 'process' may be reflective of the different perspectives, analyses, and expertise provided by the members of each research team.

The cognitive levels of interaction in VSG were higher than that observed in the instructor's classroom teaching. Whilst this may be due in part to the calibre of students that have volunteered to participate in this project, the approach utilised was characterised by several qualities that may also have strongly contributed to the learning outcomes:

- student-centred collaborative approach;
- open-ended scientific inquiry process;
- the creation of a strong online community of students and instructor; and
- contextual visualisations.

Charlin and colleagues (Charlin, Maun and Hansen 1998) emphasise a learner-centred approach towards problem-solving as being of key importance, and define four principles related to their effect on learning:

1. Learners are active processors of information;
2. Prior knowledge is activated and new knowledge is built on it;
3. Knowledge is acquired in a meaningful context; and
4. Learners have opportunities for elaboration and organisation of knowledge.

These principles are indeed reflective of the importance of contextual relevance for students who are presented with an abstract concept like genomics (Chinn and Malhotra 2002; Tobias and Hake 1988). The dialogue amongst students and between student and instructor revealed that the principles were indeed effectively utilised.

Analysis of the instructor's role in VSG

The instructor in a student-centred learning environment takes on new roles that are crucial in maintaining an interaction and collaboration amongst students. Technology-based learning communities like VSG where learning is dependent upon a socially interactive and collaborative experience are guided by a social constructivist approach to teaching and learning (Blanton Moorman and Trathern 1998; Duffy and Cunningham 1996; Jonassen and Reeves 1996; Maor and Taylor 1995; Tobin 1993). Student cognition via a social constructivist approach takes place within a social context and collaboration is an essential component. In such an environment, the instructor functions in several capacities: pedagogy; social interaction; management and technology (Bonk, Kirkley, Hara and Dennen 2001) Initial analysis of the instructor's contributions toward student team discussions revealed that my role as facilitator/motivator was nearly as prevalent as my pedagogical role (see Figure 5). This is markedly distinct from what occurs in face-to-face teaching. Reflections on this evidence of the various functions I fulfilled in this online community will formulate a more metacognitive approach for future projects.

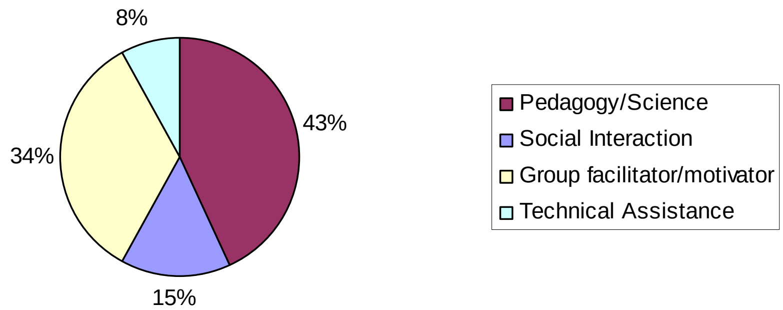

Figure 5. Roles of the instructor in the Discussion and Feedback forum

Reflections on metavisual cognition

One of the components of the VSG project was the integration of visualisations into contextual learning. The students were able to comprehend, analyse and apply abstract concepts through visual application of this abstract information. During the analysis of dialogic evidence, it became apparent that visual literacy would have played a significant role in student learning. Differences in the metavisual cognitive ability of the students would affect their ability to interpret and manipulate visual representations of their data.

> Yes. Personally I understand things more readily through pictures and graphical representation, so I think Protein Explorer and Biology Workbench helped a lot in my understanding of genomic data. *(student quote on feedback evaluation question: Did the use of visualisation tools such as Protein Explorer and Biology Workbench facilitate your understanding in the application of genomic data? Please elaborate.)*

While chemistry educators have extensively characterised student visuospatial abilities and student learning (for example see Wu and Shah 2004 and references therein), this is an area seldom considered in teaching in the biological sciences. According to Christopherson (1997), visual literacy includes the ability to interpret and comprehend the meaning and significance of visual representations, effective communication through the application of the basic principles and concepts of visual design, the production of visual messages through appropriate technologies, and the application of visual thinking toward problem-solving. Students' metavisual competence may differ significantly within the context of a project like VSG. I would venture to propose that metavisual competence in the area of genomics encompasses the following practices:

- recognition and comprehension of modes of visual representation of genomic data;
- communication of genomic information through visual representation;
- comparative application of visual representations between sets of genomic data;
- transfer of genomic information from one visual mode of representation into another visual mode of representation;
- development of models representing relationships based on quantitative and/or qualitative comparisons of visual genomic data analysis; and
- predictions of behaviour of new genomic data based on previous visual models.

These skills are gradually acquired through active experience in genomics research, whereby the researcher's understanding evolves as knowledge is synthesised within appropriate contexts. However, the learner who does not have the opportunity to access this experiential learning must develop these metavisual skills through alternate frameworks that are often subject to limitations of time and resources. To ultimately facilitate visual literacy at this level, it is imperative to ensure that the process is appropriately scaffolded by assessing competence in 'prerequisite' visual literacy in the genomic context. That is, in order to perform cognitive operations in a spatial domain, the learner must be competent in the visuospatial skills that are required for each of the conceptual steps that comprise genomics visual literacy.

In summary, emphasis on the process of inquiry through open-ended collaborative projects like VSG can facilitate students' metacognitive awareness of the scientific method. The collaborative effort was further strengthened through the creation of an online learning community that reflected a constructivist approach to teaching. Furthermore, metavisual cognition is a process that needs to be developed in parallel with scientific cognitive scaffolding; this may be an increasingly significant issue to be addressed in consideration of the challenges we face in employing visual representations of information-rich data when teaching genomics and related topics in systems biology.

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