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Using Asynchronous, Online Discussion Forums to Explore How Life Sciences Students Approach an Ill-Structured Problem

ABSTRACT

To foster students' learning of critical-thinking skills, I previously introduced ill-structured problems to provide students opportunities to apply content knowledge and thinking skills. However, I noted that my third-year, life sciences students were not solving such problems effectively. Therefore, I used a grounded approach and conducted content analysis of students' forum discussions to understand their problem-solving approaches. The students worked in small groups using asynchronous, online discussion forums (AODFs) to discuss their approaches to solving an ill-structured problem posed. Each group submitted their solution to the problem in an essay. From my analysis of students' posts at AODFs, students seemed fairly competent in using domain-specific knowledge and certain domain-general skills in scientific argumentation. However, they lacked the ability to properly define the problem scope and, consequently, failed to address the problem adequately. The study illuminated students' challenges and provided me possible ways to plan relevant scaffolds in subsequent iterations of the activity.

KEYWORDS

ill-structured problems, problem scope, asynchronous online discussion forum, feedback, grounded theory

INTRODUCTION

Fostering learning of higher-order thinking skills (Resnick 1987) is one aspect of higher education that is still a major concern (Arum and Roksa 2011; Belkin 2015), given that there seems to be no singular method of ensuring student training in that regard. An early proponent of science education reform, Joseph Schwab proposed that science education should be modelled after the normal process of how scientific knowledge is constructed through scientific inquiry (Schwab 1960). Schwab proposed that new materials should be developed in which the process of scientific inquiry is integral to the science lessons and not a supplemental part. These ideas have since been echoed by science educators and different strategies have been proposed to incorporate them into teaching and learning activities such as in biology courses (Brewer and Smith 2011).

Part of scientific inquiry is problem solving, especially solving ill-structured problems (Jonassen, 1997). Incorporating opportunities for solving problems can support learning skills associated with the practice of scientific inquiry, including undertaking critical analysis, justifying statements of claims, and rebutting and defending claims (Schwab 1960). Indeed, ill-structured problems have been used previously for science teaching at various levels (e.g. Kim et al. 2012; Shin, Jonassen, and McGee 2003) and is especially important at the tertiary level (Hung and Amida 2020).

In my life sciences module, I previously provided opportunities for students to work individually on answering an ill-structured question based on analysis of scientific data. During past semesters, I noted that students generally lacked the ability to adequately address the problems posed. For instance, students missed the main point of the question, and consequently, provided answers that were tangential to the problem.

To discover strategies students employ to solve ill-structured problems, I redesigned the assignment so that students discussed their solutions using asynchronous online discussion forums (AODFs). I took a grounded approach to conduct content analysis of students' discussion threads captured at the AODFs to obtain information that would help me design scaffolds for students to learn problem-solving skills in subsequent classes.

THEORETICAL BACKGROUND

Using ill-structured problems as a teaching and learning tool in life sciences

The relationship between problem solving and learning is one where problem solving is the performative step that will make explicit what students have learned (Anderson 1993). According to Anderson (1993), problem solving is the application of learned declarative knowledge together with procedural knowledge onto a question in order to provide a solution. Moreover, problem solving has been conceptualised as the process that activates the use of various high-order cognitive processes, an ideal encompassed in the aims of a good education (Jonassen 1997), especially for higher education (Hung and Amida 2020; Resnick 1987). The links among problem solving, learning, and thinking therefore make it worthwhile to design problems for students to practise and demonstrate content knowledge and skills they had acquired. Furthermore, there could be opportunities to learn collaboratively while solving problems.

The structured nature of problems used for student learning have been classified along a continuum from well-structured to ill-structured (Simon 1977). A framework for analysing the characteristics of a problem can be useful for guiding the instructional design of courses incorporating the use of ill-structured problems (Jonassen, 2011). In his framework, Jonassen suggested five characteristics that define a problem type, including structuredness, context, complexity, dynamicity, and domain specificity (see also figure 1).

In terms of structuredness, ill-structured problems generally do not clearly present all of the information needed for resolution. Consequently, ill-structured problems require students to use concepts from different domain knowledge, and have more than one possible solution. In terms of context, a situation that is relatively similar to what research scientists do could be designed for students in fields where evidence-based decision-making is important, such as making decisions based on evaluation of research data. Moreover, complexity could be incorporated by increasing the connections among issues students have to grapple with as they address the problem posed. As compared to well-structured problems, the use of contextualised, open-ended problems is particularly pertinent because students require broader and higher-order skill sets to work (Hmelo-Silver 2004). Dynamicity refers to the inter-relationships between issues in a problem and how they might change over time. This is an important aspect of problem solving as solutions initially identified might require adaptations to suit changes.

Ill-structured problems can therefore be used for teaching and learning to foster higher-order thinking. For instance, solving ill-structured problems requires scope identification of the problem (Jonassen 2011). This includes understanding the meaning of the information and the context of the problem. Properly representing information in some form of relationship between the problem elements is useful for understanding what the problem entails as this allows one to search for appropriate solutions for the problem. Indeed, students' problem-solving skills can be improved through providing a context in which they can apply their skill (Yu, Fan, and Lin 2015). Good predictors of problem solving therefore include both domain-specific knowledge (field of study) and domain-general knowledge (logical thinking) (Shin, Jnoassen, and McGee 2003). These important aspects of higher education related to knowledge and skill transfer require students to learn how to activate old and new knowledge or experiences when solving problems in particular situations (Voss 1987).

Ill-structured problems are important for life sciences teaching as they reflect the characteristics of authentic scientific issues (Aikenhead 1996; Schwab 1960) and provide students opportunities to practise ill-structured, problem-solving strategies. Indeed, life sciences students exposed to open-ended questions showed gains in their abilities to deal with such questions (Tsaushu et al. 2012). Furthermore, as ill-structured, problem-solving activities have been used in different fields such as engineering, astronomy, education technology, psychology, and engineering ethics (e.g. Byun, Lee, and Cerreto 2013; Chen and Bradshaw 2007; Choi and Lee 2009; Dringenberg and Purzer 2018; Ge and Land 2003; Jonassen et al. 2009; Shin, Jnoassen, and McGee 2003), it is possible that problem-solving strategies are transferable and relevant not only for life sciences undergraduates.

Social-cultural theory of learning

While it is essential to incorporate problem solving to augment learning, students might learn better when solving problems in collaboration with others. This idea is supported by the social-cultural theory of learning proposed by Vygotsky where learners learn through social interactions and in a context-dependent manner (Kozulin et al. 2003). This formed the basis of his concept of the zone of proximal development (ZPD) (Vygotsky 1980) where the learner shows a higher level of development when guided by an adult or more capable peers than by working independently (Daniels 2005).

For instance, students might construct new understandings based on prior knowledge and this learning might be further enhanced through collaborations with peers or the instructor to develop expertise in the field (DeHaan 2005). In that light, the community provides the scaffolding for student learning and also for creating the ZPD (Vygotsky 1980) so students can develop beyond their initial capabilities.

It should be highlighted that while undergraduates are not all likely to be discovering new knowledge *per se* while working on ill-structured problems as compared to a community of professional scientists working on new discoveries (Gil-pérez et al. 2002), this exercise nonetheless provides an opportunity for them to devise a solution to a given problem based on their prior knowledge. The idea of constructivist learning (Tobias and Duffy 2009) in this sense would be for students to develop solutions to an open-ended problem for themselves, and then to collaborate with their discussion group on extending their ideas together.

AODFs can be effective for student learning in a collaborative manner (Hrastinski 2009), provided assignments are carefully constructed to elicit discussions (Andresen 2009; Gao, Zhang, and Franklin 2012). Indeed, AODFs have been used in a wide range of settings and have been shown to improve student engagement (Galikyan and Admiraal 2019); interactions among students and students with staff (Osborne et al. 2018); scientific argumentation (Choi and Hand 2019); and performance in assessments (Jorczak and Dupuis 2014; Malkin, Rehfeldt, and Shayter 2018), among other learning outcomes.

More specifically, AODFs have been used as a platform for students to reflect and learn from one another as they solve ill-structured problems (Kolb and Kolb 2005; Ng, Cheung, and Hew 2010; Ng and Tan 2006; Xie and Bradshaw 2008). Using AODFs to mediate solving ill-structured problems may provide a useful way to support interactive learning among students if time and class sizes are constraints.

AIM OF THE STUDY

The aim of the study was to discover how my third-year life sciences undergraduates negotiate their way through an ill-structured problem. The findings can be used to develop better scaffolds to help life sciences undergraduates improve their problem-solving skills.

The research questions for the study were:

1. Did using an online discussion forum make explicit students' problem-solving approaches?
2. If at all, what problem-solving approaches did life sciences undergraduates use when they are faced with ill-structured problems?
3. Based on the analysis, how can I improve my instructional design to help support students' problem-solving strategies?

METHODS

Module information

At the National Univeristy of Singapore, I taught a a third-year, undergraduate elective module called Molecular Basis of Diseases. This is a face-to-face module and I taught a third of the syllabus in 2015 on the topic of the molecular basis of cancer. My teaching spanned six weeks and the discussion forums, which constituted one online component of the module, began after my first lecture. The AODFs were held using the institutional Integrated Virtual Learning Environment (IVLE).

Assignment for online discussion

To ensure that the problem posed was sufficiently open-ended, I mapped the problem onto Jonassen's five characteristics of the structuredness of a problem (Jonassen 2011) (figure 1). The problem used for the forum discussion asked students if they agreed with the thesis that "the promoter hyper-methylation of the CHFR gene is tightly correlated with colon cancers." CHFR is a gene that encodes a protein that regulates cell division by delaying division if there are errors in the process. Students selected three out of four articles provided to read as part of the exercise to address the question.

Figure 1. Criteria for judging structuredness of assignment

Criteria for ill-structured question	Comments on the level of structuredness in the question posed for students to work on at the discussion forum
Structuredness	Ill-structured as students could decide to make different stands including agreeing, disagreeing, agreeing to different extents based on the use of different combinations of articles.
Context	This was based on an authentic context of how researchers normally have to deal with ambiguities in clinical data to make evaluations.
Complexity	There is a level of complexity involved in the question for the forum discussion as the students had to analyse data from cell lines and clinical samples, as well as to evaluate the data on the issues of relevant controls, sample size, statistical significance, and correlations between promoter hypermethylation and colon cancers.
Domain specificity	There is a requirement for domain-specific knowledge related to cancer biology, tumour suppressors, promoter hypermethylation, and laboratory techniques, among others. In terms of domain-general knowledge and skills including problem-solving and communication skills.
Dynamicity	There is also some level of dynamicity as students have to respond to one another's posts to their own solution to the problem, as well as to the instructor's comments on their proposed solutions.

The students in the class were organised into groups of three to solve the problem. They discussed their solutions to the problems in their groups using AODFs. One week before the assignment deadline, each group could submit a draft group essay to explain their solution.

The instructor did not intervene in the AODFs, but she provided feedback once to each group on their draft essays. Students had time to continue their discussions using the AODFs and revise their essays before the final submission. The feedback was provided to students in their forum groups and mostly pointed students to the different aspects of the problem-solving steps as a scaffold for them to address areas that were deficient in their draft essays. Students were provided a rubric of the marking scheme indicating the weightage (figure 2).

Figure 2. Weightage in the assignment

Criteria	3 marks	2 marks	1 mark	0 mark
Ability to articulate solution to the question	Able to express clearly, in own words, solutions to the question in a coherent manner	Able to list down examples that might be relevant to question, though the relationship between the examples and question might not be made clear	Absent most of the time from discussion and provide superficial suggestions	Absent
Use of supporting data	Able to provide very relevant data to support ideas used to address the question	Able to provide only limited or irrelevant data to support ideas used to address the question	Absent most of the time from discussion and provide superficial suggestions	Absent
Ability to interact with other classmates with respect to their posts	Able to respond to others in constructive manner and offer alternative perspectives	Limited constructive interactions with other group mates' comments	Absent most of the time from discussion and provide only superficial suggestions	Absent

Note. Shown here is the grading rubric for the discussions at the AODFs. Students were awarded four marks for their forum posts and six marks for their essays.

Student recruitment

There were 61 students in the class with twice as many female students as male. There were five exchange students with the rest being local life sciences majors. Of the local students, 50 were third-year while six were fourth-year students. For student recruitment, a support staff not involved with students in the module emailed them the participant information sheet and consent form. We also provided students hardcopies of the documents for their signatures should they consent to participate in our study. The support staff collected the consent forms from the students and upon completion of the course determined which student posts could be used for the analysis. During the semester, it was not made known to me which students had consented to participate in the study.

Documentary analysis

Forum data collection

The study was approved by the university's Institutional Review Board (B-15-035). After the semester, I downloaded the discussion forums from our IVLE as text files.

Coding

I performed the content analysis with coding and quantitation (Cohen, Manion, and Morrison 2011) of the various categories of arguments. As stated by Marra and colleagues (Marra, Moore, and Klimczak 2004), "Content analysis of computer-mediated conferencing aims to derive meaningful objects from a *corpus* of teleconferencing messages. It is a tool which educators need if they are to decode and understand the mental processes involved in this kind of learning." As AODF was a form of computer-mediated conferencing tool where exchanges can be made among participants online, I attempted to derive meaning from the students' posts with an emphasis on how they tried to solve the ill-structured question.

I used the grounded approach based on Strauss' thesis for the content analysis (Strauss, 1987b). The unit of analysis for coding was individual sentences for each post (Rourke, Anderson, Garrison, and Archer 2001; Strijbos et al. 2006), with the assumption that each sentence "can be regarded as 'meaningful in itself, regardless of the meaning of the coding categories'" (Strijbos et al. 2006). While a grounded approach was taken, I analysed the forum discussions with a lens to understand problem-solving strategies while working collaboratively on an ill-structured problem. Essentially, I judged students' written sentences as "empirical indicators" of their "behavioural actions" towards solving the problem.

In using this approach, I first interpreted students' posts on the AODFs as to what they were attempting to achieve during their exchanges and coded them. From these codes, I looked for common themes that emerged and collapsed similar themes together into "concepts" (as proposed by Strauss' "concept-indicator model" [Strauss 1987a]) or categories (Bryant and Charmaz 2007b). These categories provided a better overview of students' problem-solving approaches without being overwhelmed by the numerous posts. The freeware, TAMS Analyzer, was used for coding.

Quantitative analysis

Descriptive statistics, such as frequency distributions of students' posts across time, were used to understand broad tendencies of students when undertaking problem-solving tasks. Descriptive statistics, together with content analysis, could be helpful in providing insights into the collaborative nature of students problem-solving strategies (Schrire 2006).

RESULTS AND DISCUSSION

Question design for forum discussion

To ascertain the structuredness of the problem I posed for students, I evaluated my problem using Jonassen's framework (2011). Figure 1 shows the analysis of the problem in relation to its "ill-structuredness." For instance, the question allowed students to take different stands on the statement depending on their definition of the term "tightly correlated" and the data within the articles they chose to read. The data in the four research articles provided included ambiguities, and required students to define the problem space clearly. This aspect of critical analysis of data mirrored an authentic problem with a relevant context in clinical research.

The question further required students to rely on both domain-specific and domain-general skills, including understanding the function of CHFR; relationship between defective cell division and cancer; and problem-solving skills, respectively. Therefore, there was a level of complexity higher than the typical textbook questions our students are asked to answer. In addition, students had to respond to one another's comments and to the instructor's comments, providing some level of dynamicity in their approach to solving the problem. Mapping my life sciences question onto the framework (Jonassen 2011) allowed me to ensure that my question was ill-structured and suited my needs. Such a framework could also be useful for other fields as it focuses on the problem characteristics in a domain-independent way.

As the problem was ill-structured, students were asked to take a position in relation to the statement. For instance, one student wrote, "I would have to generally agree with the statement that 'Hypermethylation of the CHFR promoter is tightly correlated with colon cancers,' with a few reservations," while another stated, "Overall I say that we disagree with the question because I think that just by looking at these three studies alone, its not possible for us to determine a tight correlation." Other students had varying degrees of agreement with the thesis depending on the articles they chose to read. Hence, students could not merely rely on standard answers taken from references. They had to rely on domain-specific knowledge to understand content knowledge and assess the data using domain-general skills to argue their case.

Observations on forum discussions revealed general approaches students took when considering a problem

Overview of the coding data, concepts and themes

I analysed 16 out of 20 groups, with various groups having one, two, or all members who consented to the study. Group 12 was omitted due to irreparable damage in the file. The sentences from students' posts on the forums were interpreted as behaviours suggesting approaches to dealing with the ill-structured problem, including responding to one another's posts and organising tasks among group-mates. They were coded accordingly. The distribution frequencies of codes and key themes that emerged are elaborated below.

Distribution frequencies of codes from various forums

The overall frequencies of codes per discussion group are shown in figure 3a. The participation of the students started on 23rd March and ended on 10th April, which was the deadline for the essay submission (figure 3b). From the frequency distributions, there was no correlation between the number of students per group and the number of codes that could be derived from their posts. The number of students per group was as small as two without compromising the number of codes. This might be due to individual marks being awarded for contributing to the AODFs that led to a high level of student participation. For instance, the number of posts from each student was rather high, with more than 20 each for the students I analysed (figure 3c). Previously, when I set up an optional forum with no participation marks awarded for student posts there was no participation.

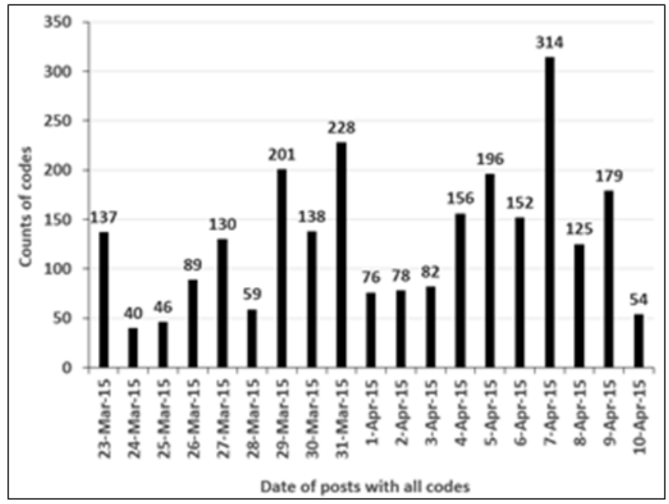
Several groups had roughly even numbers of contributions by all group members while others, such as group four, had one student posting more frequently than others. Selected students and the number of posts made are shown in figure 3c to provide some indication of the differences in number of posts among students. On one extreme, one student contributed more than 200 posts. On the other extreme, one student had fewer than five inputs at his group forum. It turned out that the student was troubled by personal matters. Subsequently, it would be useful to understand difficulties faced by students who contribute far fewer posts than other members in their groups, such as by the instructor intervening earlier in the forums to monitor participation (Hou 2011; Parks-Stamm, Zafonte, and Palenque 2017).

Figure 3. Frequency distribution of codes

(a)

Forum number	Number of students analysed per forum	Number of codes analysed
Forum 3	3	363
Forum 4	3	169
Forum 5	3	312
Forum 6	1	94
Forum 7	3	268
Forum 8	3	44
Forum 9	2	189
Forum 10	2	282
Forum 13	3	250
Forum 14	1	84
Forum 15	2	152
Forum 16	3	146
Forum 17	2	168
Forum 18	1	71
Forum 19	2	425
Forum 20	2	127
Total counts	**36**	**3144**

(b)



(c)

Student	Number of posts
Student 4 (forum 4)	108
Student 5 (forum 4)	41
Student 6 (forum 4)	23
Student 11 (forum7)	63
Student 12 (forum 7)	52
Student 13 (forum 7)	78
Student 32 (forum 19)	210
Student 33 (forum 19)	148

Note. (a) Frequencies of codes per discussion group. Students were grouped into forums, with each forum assigned a unique number. The total number of codes derived from the posts are shown. (b) Overview of student posts over the duration of the assignment, from weeks 9 to 12 of the 13-week semester. The number of codes derived from the posts were counted across the period indicated. (c) Number of posts by various students in groups. Students were assigned unique numbers within each forum and the total number of posts by selected students are shown.

Codes and core categories that emerged

To illustrate how I collapsed codes into categories, I use here an example of how I coded student posts concerning the use of the data in the research articles provided when trying to solve the problem posed. Students' exchanges included data descriptions, summaries, or critiques, and use of data for arguments. These were coded as "description," "critique," and "argument" to form sub-categories (Bryant and Charmaz 2007a) under the category of "Data." In the TAMS Analyzer software, the categories and sub-categories were denoted as: "Data>description," "Data>critique," or "Data>against_argument>cells." In the last example, there was a sub-sub-category of data concerning cells that were used in a student's argument. The use of different levels of sub-categories helped enrich the coding of the data as they provided finer details of students' activities at the forums.

By systematically coding students' posts, a few core categories (Strauss 1987a) emerged that represented overarching characteristics of students solving the ill-structured problem. These core categories were "Information processing at a surface level," "Information evaluation," "Addressing question posed," and "Student interactions." I derived these theoretical core categories based on constantly comparing the various categories conceptualised from the coded data (Glaser 2008). Again, using the example of the category of "Data," I included a few sub-categories under "Data" in the core category of "Information processing at a surface level" (appendix A). The core category of "Information processing at a surface level" also contained codes from other categories and sub-categories within, further illustrating my interpretation of students' attempts to solve the problem with surface-level information processing. Supplemental figure 1 shows the various categories that have been organised into the four main core categories.

Given the large number of codes and sub-categories within each of the core categories, I will focus attention in the following sections on a few aspects within each that helped illuminate students' strengths and weaknesses in this assignment. This is also relevant for designing scaffolds to help students learn problem-solving skills in subsequent semesters.

Information processing at a surface level

At the outset, students spent a significant amount of effort at the forum describing data from the research papers they were reading, with 264 codes assigned to "Data>description" as seen from the top 20 most frequent codes (figure 4 and appendix B). These posts were mostly straightforward accounts of background information, technical details of experiments, and summary of data in the research articles.

Figure 4. Top 20 most frequently observed codes

Number of students analysed	36
Data>description	263
topic	223
date	221
student	215
Suggesting>action	185
Evaluating_statements>critique_data	151
Heading	139
Non_task_comment	103
Information_background	87
Technique>description	70
Action	60
Information_on_CHFR	57
Data>supporting_argument>biopsies	53
Suggesting>approach>using_data	47
Technique>explanation	46
Consensus	46
Reasoning_statements	46
Data>explanation	46
Comment_on_others_work	45
Trying_to_distinguish_cells_tissues	42

This pattern of sharing and comparing information formed the basis for my students' early responses to the assignment, and can be considered a positive outcome of the assignment. It was unusual for most students to read about clinical research work as they were mainly exposed to molecular and cell biology research articles that are normally different in terms of the research methodologies. Students in our modules also generally did not have many opportunities to assess what constituted critical information they needed to share with classmates and have their written work read and used by their peers for an assignment. Students' efforts could be conceptualised as their initial attempts at processing and exchanging information, albeit at a surface level.

Nonetheless, this was in line with the first of a three-step process of Henri's concept of interactivity (Henri 1992) where information was communicated followed by responding to the information. This was also similar to phase I of the interaction analysis framework proposed previously in a study on computer conferencing (Gunawardena, Lowe, and Anderson 1997). My observations implied that students regarded information processing and presentation (Shin, Jonassen, and McGee 2003) as the initial steps towards working collaboratively to solve the question.

Information evaluation

Students' posts also included explaining data, providing critiques of data, and justifying the use of relevant data to support their arguments. These activities represented part of students' intention to support or refute possible solutions to the assignment question. Generally, the quality of students' analyses of the data was fairly good, despite their limited exposure to clinical research articles. For such analyses, students demonstrated various aspects of domain-specific and domain-general skills.

For instance, a student who wrote that "Alternatively, it means increased incidence of colon cancer recurrence with high CHFR methylation" required an understanding of concepts of cancer recurrence and links to promoter hypermethylation of tumour suppressor genes such as CHFR. This is domain-specific knowledge related to my lessons. Another student wrote that "Results gathered may not be accurate due to the small sample size." This assertion was independent of concepts I introduced directly in class and suggested that he applied general skills to assess the data presented.

Students were able to cite specific data further, such as frequency distributions reported in the articles as a means of substantiating their point when agreeing or disagreeing with groupmates. For instance, one student cited "68% of all primary cancer with MLH1 promoter hypermethylation, hypermethylation of CHFR promoter was observed" while another stated "57% (12 out of 21) of colon tumour cell lines displayed undetectable or low levels of CHFR expression." The latter example highlighted the issue where students did not seem able to distinguish between patients' tissue biopsies from cell line data when addressing the question. This highlighted to me a deficiency that students had in defining the scope of the question. As I had phrased it, the question required students to discuss whether they should focus on tissue biopsies or on cell lines. This is pertinent to the scoping step of solving an ill-structured problem and is addressed below. Nonetheless, students' usage of data to support their claim indicated their ability to argue their stand in their effort to solve the problem. Argumentation is an essential skill for science students (Osborne 2010) and is a crucial element of problem solving (Jonassen 1997).

I included students' activities revolving around the analysis and critique of the data (Shin, Jonassen, and McGee 2003) under the core category of "information evaluation," since students were trying to interpret and apply the data to solve the problem. These behaviours were situated at the higher levels of Bloom's taxonomy (Wood 2009), such as analysis and evaluation. This implied that the ill-structured question could have promoted deeper thinking among students as they collaborated on addressing the question and is consistent with phase II of the online, interaction analysis model (Gunawardena, Lowe, and Anderson 1997).

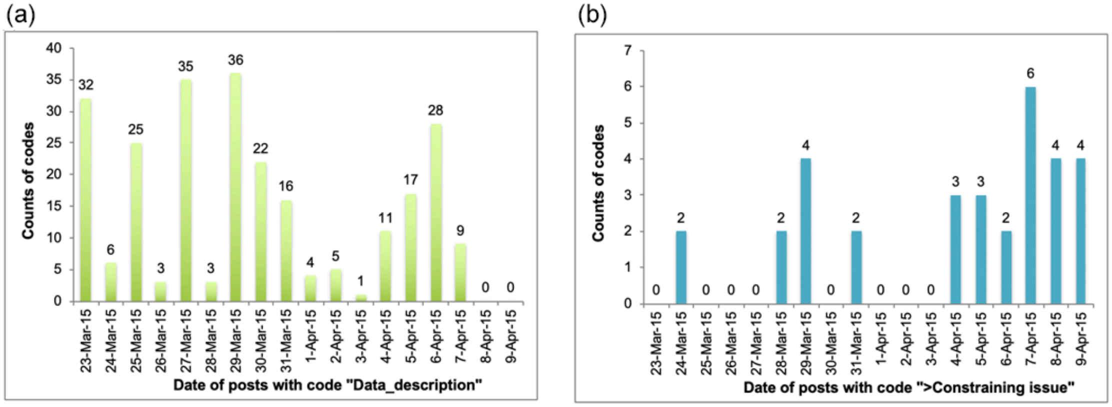
Identifying key issues of an ill-structured problem

In the context of our ill-structured question, students were expected to deconstruct the problem, such as defining terms in the question, before they embarked on discussing the data. Key words, such as "tightly," "correlated," and "colon cancers," when properly defined, would help them focus on the pertinent data in the articles that they selected. According to Jonassen (2011), the initial step to addressing a problem is identifying the scope of the question. Similarly, Xun and Land (2004) have suggested that there needs to be "problem representation" to determine the constraints of an ill-structured problem in order to develop possible solutions.

From my analysis, students generally failed to discriminate between the data on cell lines and patients' biopsies for the question on "colon cancers." Cell lines are cells in culture that have been propagated over a long time, do not reflect the characteristics of cells taken recently from patients, and serve as useful tools in laboratory experimentation. Biopsies or tissues taken from patients provide information on actual patients' cancer profiles or characteristics; are used for diagnostic or prognostic evaluations; and are relevant to the problem posed. The inability to distinguish between the types of samples could be due to a lack of attention paid to identify the scope of the problem posed since I had explained the differences in class. Instead of possibly discussing the various stages of colon cancers, a number of students focused on cell lines without explaining how cell lines could be relevant to the question. By not properly defining the scope of the problem posed to them, the solutions students proposed were therefore tangential or irrelevant to the problem.

Relative to delving into data description early on in the assignment (figure 5a), students attempted to define the scope of issues later in the discussions (figure 5b). In some cases, students did it only in response to the instructor's comments. For instance, in my feedback on April 6 to students from group nine on their draft essay, I prompted them to looking closer at key words and phrases in the problem so that they could consider defining the problem scope. This led to exchanges between two students from group nine during which they started to focus on what the term "tightly correlated" meant in the question after my feedback. Although the post between the two students was not analysed because consent was not given by the third student, I noted that students grappling with the criteria to define what constituted "tightly correlated."

Figure 5. Timeline of students' posts showing predominance of students delving into data description (a) as opposed to constraining the issues before addressing question (b)



Only one student from group seven stated the need to focus on pertinent issues in the question posed early in the assignment (figure 6). This student proposed some criteria the group could use to define the terms "hypermethylation" and "correlation," and the relevant data that they could use from the articles to determine what this could entail.

Figure 6. Student who defined terms early on in the assignment

Topic: Discussion for Essay
From:
Date: 28-Mar-2015 12:24 PM

Let me try to figure out what the question is asking and also give my opinion on the question based on my article (Toyota et al. 2003) so we can sort of start on the essay.

"Hypermethylation of the CHFR promoter is tightly correlated with colon cancers"

a) Hypermethylation: I think that because of this word, we should only use examples that talk about "dense methylation" (my article uses this phrase) instead of "partial methylation"? Or maybe we could use the examples of partial methylation and no methylation to rebut the question, i.e. when the CHFR promoter is unmethylated, there's a weak correlation with colon cancers.

b) Tightly correlated: I guess the easiest way to interpret this is by using statistical significance. My article doesn't use statistics but other experiments to explain this correlation. Do any of yours use statistics to explain the correlation?

Overall, there was a tendency for most students to immediately summarise the data in each of the scientific research articles provided rather than attempt to define terms and criteria for the assignment. These observations suggest that it would be worth designing scaffolds (Tawfik et al. 2018), such as providing question prompts to help students develop problem-solving skills (Xie and Bradshaw 2008; Xun & Land 2004) (discussed below).

Student interactions within forum groups

Our students are normally rather reticent in classes, making it difficult to assess if they were able to articulate ideas on the topics they were learning. It was therefore encouraging to note that the students were interacting with one another using the AODFs. Students responses to one another's posts ranged from "ok" to more elaborate exchanges. For example, a student responded to a query with, "But this is a good point, I think it is because the researchers are looking for an association between cancer recurrence and CHFR methylation status as a biomarker, and not so much as the epigenetic profiles of the 2nd tumor incident." Another student replying to a suggestion posted, "Hey guys I think looking at each word and trying to define each word according is fantastic and gives us a platform and guideline to start writing the essay."

These indicated various types of collaborative processes including articulation of personal viewpoints; queries; accommodation or reflection of other's perspectives; and co-construction of shared perspectives and meanings (Murphy 2004) or attempts to coordinate or utilise different perspectives (Dringenberg and Purzer 2018). This implied that using AODFs promoted a certain level of collaboration beyond exchanging information. Such processes not visible to me in normal teaching contexts were made explicit by the use of AODFs.

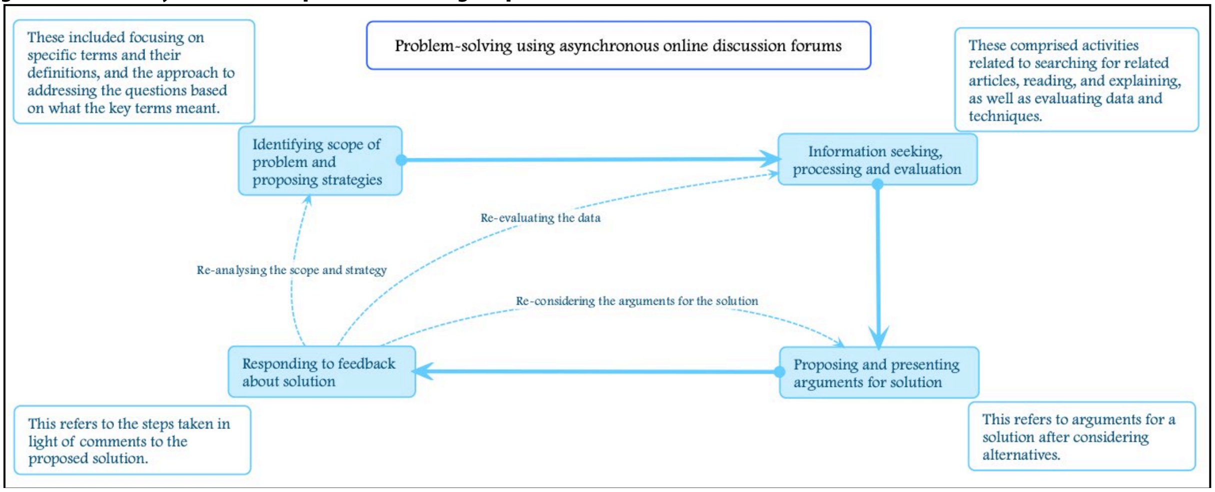
Compared to face-to-face discussions, AODFs can allow time and space for students to read and reflect before posting their thoughts after they have had time to engage with relevant materials (Wang and Woo 2007). In this example, the assigned readings provided materials for contributions and interactions among students, and allowed students to demonstrate their ability to provide information about articles they read. This allowed for the univocal function of conveying meaning correctly and hence created a "potential" for student learning (Dysthe 2002).

Moreover, it has been proposed that students benefit from different types of peer-interactions (Webb 1989), not least due to the students' engagement in activities, including constructing knowledge, examining evidence of claims, and defending their assertions among themselves (Choi and Hand 2019; Osborne et al. 2018; Schellens and Valcke 2006). Although several students had fewer codes associated with their posts as compared to their group members (figure 4c), it has been proposed that passive students might learn from the posts of other students (Ge and Land 2003). It would be useful in subsequent semesters to study how students who interact actively versus passively can benefit from the use of AODFs in problem-solving tasks.

Possible changes to instructional design

The core categories that emerged from the analysis are reflected as key steps in students' problem-solving process summarised in figure 7. Student interactions are not shown explicitly here since interactions are inherent in forum discussions. Both domain-specific and domain–general skills seemed to underpin students' work on the ill-structured problem.

Figure 1. Summary of students' problem-solving steps



Students' key weakness was scope identification of the problem. Consequently, they failed to address the problem adequately. This finding is similar to a study on pre-service teachers in our local context (Ng and Tan 2006), though another study conducted with Masters students showed that they were able to define problem space (Ng, Cheung, and Hew 2010). These data suggest that undergraduates might lack some experience in addressing critical issues in ill-structured problems and are novices compared to post-graduates or experts who are better at scoping problems (Sarsfield 2014).

From previous studies, scaffolds could be designed to help students approach problems more strategically (Jonassen 2011; Xie and Bradshaw 2008; Xun and Land 2004). Scaffolds such as question prompts (Xun and Land 2004) could be incorporated in future classes to help students formulate problem-solving strategies. Such question prompts are shown below in table 1. These questions could be provided to students at the start of the assignment to improve their understanding of how to use the problem-solving framework as they discuss solutions using AODFs.

Table 1. Question prompts adapted from Ge and Land (2003) and Jonassen (2010)

1. Problem definition
    a. What are the key issues in the problem?
    b. Are there issues/terms I have to define so as to address the problem directly?
    c. What are the boundaries of the issues which I need to deal with?
2. Solution development
    a. What are the possible solutions to the issues in the problem?
    b. What are the arguments for and/or against my proposed solutions?
3. Solution critique
    a. Are there alternative solutions?
    b. What are the arguments for and/or against my proposed solutions?
4. Implement and evaluate solution
    a. Are the solutions working?
    b. Is there feedback on the solutions?
    c. How do we adapt the solution based on the feedback?

Furthermore, getting students to understand the whole process of problem solving in the form of threshold concepts (Wismath, Orr, and Mackay, 2015) could be beneficial. I could include exemplars for students to practise solving problems in a sequence of steps prior to the assignment to promote persistence at problem solving, fostering collaborative-learning through low-risk marking, and modelling solutions early on in the process by getting students to reflect on their own processes. Additionally, I could incorporate prompts about structural knowledge within the domain-specific topics (Chen and Bradshaw 2007; Kim and Lim 2019) to help students consolidate their content knowledge so they apply their knowledge in an integrated manner.

Interestingly, even though the instructor provided limited scaffolding for solving ill-structured problems, students overall were able to demonstrate different aspects of problem-solving skills. Students also attempted to make modifications to their solutions after receiving comments from the instructor. Instructor feedback (Land 2000) could therefore be one additional component of the scaffold that could be incorporated in future semesters given that responding to feedback concerning the solution is a critical step in successfully resolving a problem (Jonassen 2011). Recent studies indicate that novices require comprehensive scaffolding (Tawfik et al. 2018), and that both rubrics and instructor prompts can elicit higher critical thinking skills and improve learning achievement (Giacumo and Savenye 2020), especially in small classes (Parks-Stamm, Zafonte, and Palenque 2017), supporting the approach that I intend to take in subsequent semesters.

The underlying contexts of the assignments will continue to be situated in the core discipline of the module, namely, molecular basis of diseases. This is in line with the Jonassens's design (Jonassen 2011) and also consistent with several more recent studies supporting the use of context for developing problem-solving skills (Dringenberg and Purzer 2018; Yu, Fan, and Lin 2015; Zhong and Xu 2019). Taken together, I aim to work towards providing additional scaffolding, such as placing an emphasis on structural knowledge, together with metacognitive scaffolding in terms of problem-solving procedures (Kim and Lim 2019).

CONCLUSION

This work documents my initial attempt to systematically study how life sciences undergraduates performed at solving ill-structured problems. Although this study involved only students from one semester, the number of students analysed within this cohort was about two-thirds of the class of 66 students. Moreover, there were recurrent codes and categories within this study.

I performed content analysis of students' posts at the level of sentences. While there were problems of reliability in this approach as students tended not to write proper sentences on online forums (Rourke et al. 2001), Strijbos and co-workers (2006) posited that it is more reliable to code segments of students' written work at computer-supported learning systems than coding the work in its entirety. This also appeared to be an easier approach for new coders such as myself (Strijbos et al. 2006) rather than coding using higher levels of texts such as illocutionary units as units of analysis (Rourke et al. 2001).

The close-reading of students' posts at AODFs revealed to me students' strategies, collaborative behaviour, and engagement of high-order cognition skills while negotiating an ill-structured problem with their classmates. These were similar to previous observations (e.g. Dringenberg and Purzer 2018; Murphy, 2004; Schellens and Valcke 2006). The data also revealed students' inability to properly define the scope of the problem before embarking on assigning tasks among themselves and looking for solutions for the problem.

This is the first in-depth examination of life sciences students' ill-structured problem-solving strategies at our local university. As the sole person who analysed the data, there could be issues of credibility and reliability. I addressed this concern by sampling selected posts for re-coding from time to time, and also made correlations between the students' posts and their solutions to confirm the trend I described above. Furthermore, the findings concerning students' deficiency in scoping the problem posed are consistent with my prior observations in this module.

This study may highlight the benefits of using AODF to promote problem-solving strategies for life sciences and other disciplines. Specifically, the study allowed me to identify gaps and scaffolds that would influence my instructional design in terms of helping students develop problem-solving skills. Based on this study, I have obtained funding to examine the effects of scaffolds we will employ in subsequent semesters on students' strategies to solve ill-structured problems. By helping students improve their problem-solving strategies, they may subsequently be able to adequately address pertinent issues in open-ended problems.

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ETHICS

The research was approved by the Institutional Review Board (IRB). Participation was voluntary and analysis was carried out on work by students who provided consent.

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APPENDIX A: CODES AND CORRESPONDING CATEGORIES

Information processing at a surface level	Information evaluation	Addressing question posed	Student interactions
Article>aim	Comment_on_others_work	Action>essay_structure	Acknowledging_response
Article>conclusion	Data>against_argument	Data>against_argument	Acknowledging_thanking
Article>elaboration	Data>against_argument>biopsies	Data>against_argument>biopsies	Action>analysed>data
Article>summary	Data>against_argument>cells	Data>against_argument>cells	Action>essay_structure
Article>title	Data>supporting_argument	Data>critique	Action>looked_for_information
Clarification>on_data	Data>supporting_argument>biopsies	Data>critique>limitations	Action>provided_draft>paragraph
Clarification>on_definition	Data>supporting_argument>cells	Data>supporting_argument	Action>provided_information
Clarification>on_example	Disagreement	Data>supporting_argument>biopsies	Answering_question
Clarification>on_post	Evaluating_statements	Data>supporting_argument>cells	Apologies
Clarification>on_sample_size	Evaluating_statements>approach	Evaluating_statements>approach	Citing>post_verbatim
Clarification>on_stand	Evaluating_statements>article_type	Evaluating_statements>article_type	Clarification>on_data
Clarification>on_strength_of_correlation	Evaluating_statements>critique_data	Evaluating_statements>critique_data	Clarification>on_definition
Data>CHFR_MLH1	Evaluating_statements>critique_data>example	Evaluating_statements>critique_data>example	Clarification>on_example
Data>assertion	Reasoning_statements	Focus_attention_onto_key_molecule	Clarification>on_post
Data>cell_lines	Reflecting_on_instructor_comment	Seeking_consensus	Clarification>on_sample_size
Data>colon_cancers	Reflecting_on_own_post	Seeking_others_opinion	Clarification>on_stand
Data>conclusion	Suggesting>action>correcting_error	Stating_aim_of_essay	Clarification>on_strength_of_correlation

Data>description	Technique>critique	Stating_stand	Comment_on_others_work
Data>explanation	Trying_to_distinguish_cells_tissues	Suggesting>approach	Consensus
Data>other_cancers	Trying_to_distinguish_cells_tissues>ethics	Suggesting>approach>alternative_stand	Disagreement
Data>used_inappropriately	Trying_to_distinguish_primary_established_cell lines	Suggesting>approach>CHFR_function	Explaining>action
Information>housekeeping		Suggesting>approach>conclusion	Illustration>example>calculation
Information>quoting_article		Suggesting>approach>constraining_issue	Opinion
Information_background		Suggesting>approach>critique_data	Question>action
Information_background>correlation		Suggesting>approach>critique_stand	Question>opinion
Information_background>sample_size		Suggesting>approach>defining_words	Seeking_clarification
Information_on_CHFR		Suggesting>approach>experiment	Seeking_clarification>CHFR_function
Information_source		Suggesting>approach>focusing_on_evaluating_data	Seeking_clarification>CHFR_regulation
Table>summarising		Suggesting>approach>relationships	Seeking_clarification>information
Table>summarising>background_CHRF		Suggesting>approach>stand	Seeking_clarification>on_approach
Table>summarising>background_info		Suggesting>approach>supporting_stand	Seeking_clarification>on_articles_limitations
Table>summarising>data		Suggesting>approach>using_data	Seeking_clarification>on_data
Table>summarising>			Seeking_clarification>

heading			on_definition
Technique> description			Seeking_clarification> on_strength_of_correlation
Technique> explanation			Seeking_consensus
			Seeking_housekeeping_ information
			Seeking_others_opinion

APPENDIX B: TOP 20 MOST-FREQUENTLY OBSERVED CODES BY GROUPS

Code	Forum3 .rtf	Forum 4 copy.rtf	Forum5 .rtf	Forum6 .rtfd	Forum7 .rtf	Forum8 .rtf	Forum9 .rtf	Forum10 .rtf	Forum13 .rtf	Forum14 .rtf	Forum15 .rtf	Forum16 .rtf	Forum17 .rtf	Forum18 .rtf	Forum19 .rtf	Forum20 .rtf	Total
Number of students analysed	3	3	3	1	3	3	2	2	3	1	2	3	2	1	2	2	36
Data>description	19	1	8	6	25	4	7	29	29	5	29	16	24	21	35	5	263
topic	20	15	27	10	27	2	24	19	15	10	6	6	8	2	22	10	223
date	20	14	27	10	24	2	24	19	15	10	6	6	9	2	22	11	221
student	19	13	27	10	25	2	24	18	15	10	6	6	7	2	22	9	215
Suggesting>action	12	30	32	12	18	3	5	8	10	13	2	0	18	0	8	14	185
Evaluating_statements> critique_data	9	3	7	3	21	0	1	11	5	9	4	0	0	0	61	17	151
Heading	13	1	0	2	0	0	0	1	5	3	5	22	16	13	49	9	139
Non_task_comment	27	4	4	1	5	2	5	15	21	3	2	0	0	0	8	6	103
Information_background	27	11	4	0	2	3	2	9	3	2	0	3	12	0	9	0	87
Technique>description	6	1	0	0	6	0	1	3	6	0	7	12	0	8	20	0	70
Action	5	11	19	1	3	0	4	11	3	0	0	0	1	0	1	1	60
Information_on_CHFR	4	5	6	5	2	6	0	7	3	0	2	1	5	8	1	2	57
Data>supporting_argument > biopsies	22	2	7	0	0	2	7	4	5	1	0	2	0	0	1	0	53
Suggesting>approach> using_data	2	1	2	1	2	4	4	10	2	0	1	0	4	0	13	1	47
Technique>explanation	5	0	0	0	2	0	0	0	9	0	3	12	0	3	12	0	46
Consensus	5	2	9	1	2	1	5	1	4	1	1	2	0	0	10	2	46
Reasoning_statements	4	2	4	4	3	0	3	3	4	1	12	1	0	0	0	5	46
Data>explanation	8	1	2	0	6	1	0	17	0	0	1	1	0	7	1	1	46
Comment_on_others_work	4	3	11	1	4	1	1	2	4	1	3	1	2	0	3	4	45
Trying_to_distinguish_cells_ tissues	2	0	4	0	2	0	3	2	0	0	5	6	12	0	6	0	42
Information_source	0	0	0	6	1	0	1	0	2	0	7	0	14	0	5	1	37
Data>conclusion	1	0	3	0	6	2	0	0	14	0	0	10	0	1	0	0	37
Suggesting>approach> constraining_issue	0	2	2	0	2	0	4	8	1	0	1	0	0	0	12	0	32
Acknowledging_response	4	0	2	0	0	0	5	1	8	0	1	0	1	0	8	0	30

Note. A copy fo the Forum 4 was used as the original file had an irreparable error.