

Design and Assessment of an Introductory Geomicrobiology Course for Non-Geology Majors

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ABSTRACT

Recent discoveries about the role of microorganisms in the establishment of the geological conditions in the planet have led to the development of courses in Geomicrobiology. Unfortunately, most courses are designed for students with a strong Geology background, which is a limitation for universities that lack such courses. To overcome this limitation at our university, we have designed a special topics course entitled Introductory Geomicrobiology that was offered for the first time to undergraduate students from the Biology, Marine Biology and Microbiology Programs. To attract non-geology majors the course included topics such as description of Early Earth ecosystems, search for geo-biological signatures and current approaches in the search for extra-terrestrial life forms. An active learning environment was fostered throughout the course through different activities including oral reports of research papers in the subject, followed by Gallery Runs and class discussions. Our assessment strategies, both formative and summative, revealed that such presentations were an effective way to introduce students to eight main concepts of Geomicrobiology. Student performance was stronger in group discussions than individually, with Gallery Runs as the preferred class discussion technique. Overall, our assessment system proved that the design of the course was effective in teaching Geomicrobiology to non-geology majors.

INTRODUCTION

Geomicrobiology is the study of the role that microbes play or have played in specific geological processes (Ehrlich 2002). Although Geomicrobiology studies has been around since 1887 with the initial discoveries by Winogradsky regarding H₂S reduction by Beggiatoa, the field has received wider recognition in the last decade due to discoveries about the influence of microbial activities in shaping the habitable part of our planet (Des Marais 1991). Stromatolites as the earliest geo-biological signatures and the search for life forms in Mars are among these important discoveries that are quite appealing to students (Des Marais 1991). As a response to this trend, new and diverse interdisciplinary programs such as Interactive Geosciences (University of Connecticut), Geology with Environmental Emphasis (Miami University), Geology and Geophysics (Louisiana State University), Geological and Atmospheric Sciences (Iowa State University) and Earth and Planetary Sciences (Washington University in St. Louis) have been established. All of these programs share a Geomicrobiology course to introduce main concepts of the field. While a Geology course is a prerequisite for the majority of the Geomicrobiology courses in Geology-related

programs, this is not necessarily the case in Microbiology programs. The requirement of a Geology course to teach Geomicrobiology imposes an important curricular constraint to non-geology majors that are interested in this emerging field. To overcome this barrier at the University of Puerto Rico, Humacao (UPRH) Campus, we have taken advantage of the Special Topics Course to offer the first Introductory Geomicrobiology course in Puerto Rico. The design and implementation of the course was supported through an NSF Research in Undergraduate Institution (RUI) in Geomicrobiology.

Research Description of the at Undergraduate Institution (RUI) in Geomicrobiology

The RUI in Geomicrobiology is an educational initiative that is part of a Microbial Observatory (MO) proposal established at the Cabo Rojo salterns in Cabo Rojo, Puerto Rico. The Cabo Rojo Salterns Microbial Observatory (CRSMO) is dedicated to identifying the microorganisms present in the crystallizing ponds and microbial mats that prevail at the location. Beyond the mere identification of the organisms, we study their possible role in the geological transformations that take place at the locations with special interest in the microbial mats communities (Casillas et al., 2005). Due to their colored layers and the sticky nature of the top layers, these

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microbial mats are quite appealing to our undergraduate students from different backgrounds (i.e., Geology, Microbiology, Marine Biology and Biology). By dissecting the mats the students are able to visualize the direct contact of microorganisms and the minerals associated to them. We have recently reported the use of the microbial mats as tools for promoting active and effective learning of basics concepts in Geomicrobiology (Ríos-Velazquez et al., 2007). In this study the students attended a series of workshops and described the following aspects as the most important outcomes of their participation in the RUI program: (a) the opportunity to study and learn about new and different sciences disciplines, (b) the use of microbial mats to integrate different science disciplines, and (c) the capacity to work in multidisciplinary teams to learn from their peers' disciplines' backgrounds (Ríos-Velázquez et al., 2007).

In addition, to conduct research projects and attend several workshops during the academic year, students from the RUI program also participated in summer experiences at the Marine Biology and Integrative Geosciences Departments from the University of Connecticut (UConn) in Avery Point. In the summers of 2003 and 2007 students have attended intensive Geomicrobiology workshops consisting of a week of lectures and experimental work. The experiments conducted included microscopic analysis of microbial mats, setting up enrichments for sulfate reducers and methanogenic organisms from the anoxic layers of the mats, in situ gas measurements and determination of oxygen profiles from sediments around UConn. At the end of the workshop the students were responsible for presenting their findings in oral presentations. Further information on the CRSMO research and educational initiatives can be found via the internet at the web page of the RUI program (www.uprh.edu/~salterns).

As mentioned, to complement these educational efforts we offered a Special Topics Course in Geomicrobiology to undergraduate students from the UPRH. The course was designed to introduce students to the field of Geomicrobiology using eight main topics ranging from role of microbes in Early Earth to the search of possible extraterrestrial life. In this work, we describe the objectives, structure and assessment of this new Introductory Geomicrobiology Course specifically designed for non-geology majors.

GEOMICROBIOLOGY INTRODUCTORY COURSE

Student population

A total of 13 undergraduate students enrolled in the Introductory Geomicrobiology course. Forty-six percent of the students attending were majoring in Biology, 38% in Microbiology and 15% in Marine Biology. Interestingly, only one of the students had taken Geology or a Geology related course before (Coastal Geomorphology) and four had never taken a Microbiology course. Since no pre-requisite courses were required for taking the course, the student population consisted of sophomores, juniors and seniors.

Main concepts and learning goals of the course

The Introductory Geomicrobiology Course was designed to give students a broad overview of major topics or concepts in the field. These topics were reduced to:

- Role of microbes in geological transformations of our planet
- Early Earth ecosystems and the importance of microorganism in the establishment of life on our planet
- Microbial diversity of ecosystems that simulate Early Earth development
- Search for geological signatures in our planet
- Search for biological signatures in other planets
- Regulations regarding possible contamination with extra terrestrial life forms
- Survival and resistance of life forms in extra terrestrial simulated environments
- Conditions necessarily for extra terrestrial life

The main learning goal of the course was to read, present and discuss recent research investigations that cover these eight topics, so as to provide the students basic knowledge about the role microorganisms exerts over geological transformations in our and other planets. This goal was met through an active learning environment where students discussed some of the major geological transformation of microorganisms (i.e., carbonate formation and dissolution) as well as some of the methodologies currently used to detect extraterrestrial life forms. An example of the latter was a detailed explanation of how X-Ray diffraction analysis help discern the biogenicity of certain minerals by their patterns.

The structure of the course was essential to help students understand these main concepts. On

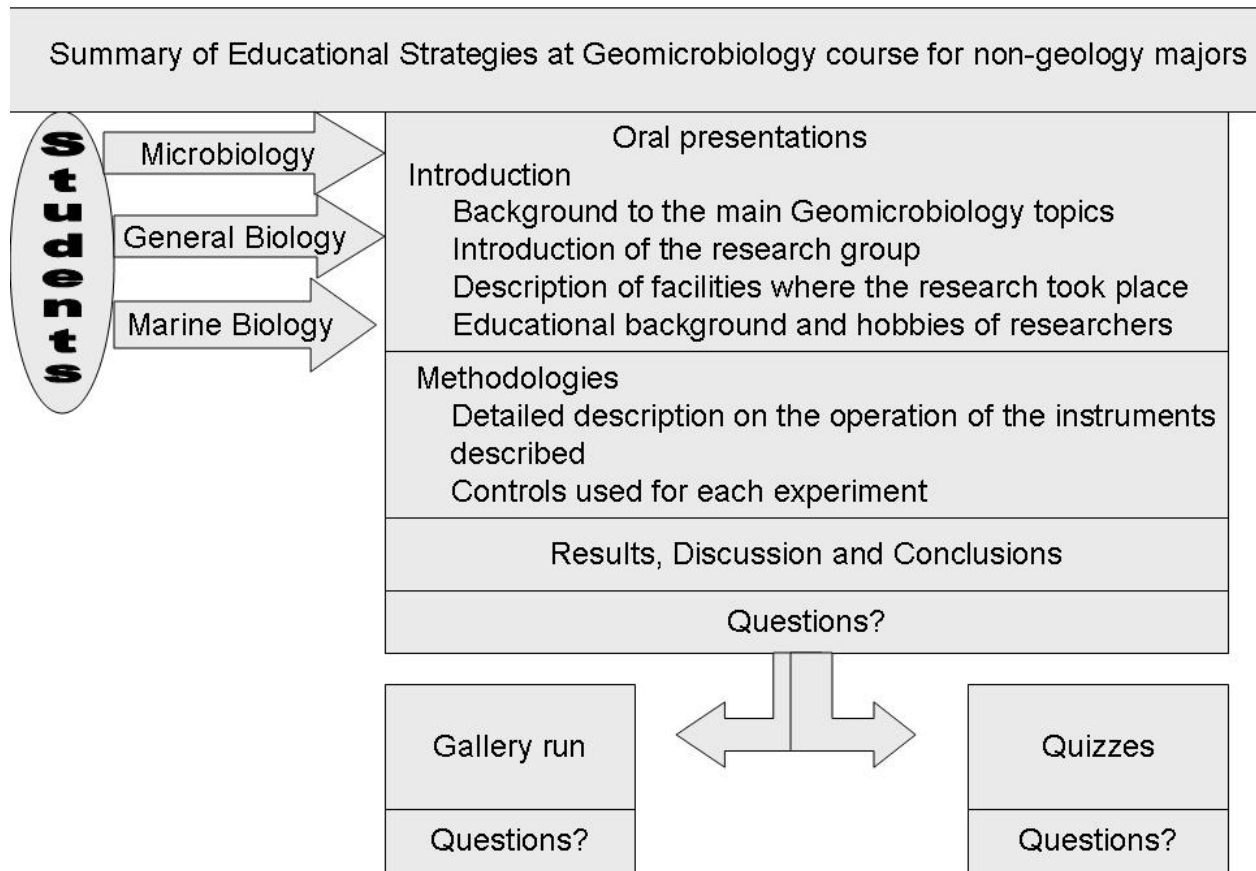


Figure 1. Summary of educational strategies used in the Introductory Geomicrobiology course offered to non-Geology majors.

the first day the PI provided a lecture about Geomicrobiology and its important implications in the Early Earth development. As four of our students have never taken a Microbiology course before, in this lecture we exposed our students to general Microbiology concepts such as the sterility and aseptic techniques required for the growth of microorganisms and requirements of media to support growth.

In subsequent classes students began the discussion of review papers such as Erlich, 1999 to explain basic concepts of Microbiology and the different mineralization reactions that take place in the microbial world, with special emphasis on the diversity of microbial forms that are responsible for them. To help students become familiarized with microbial diversity analyses we then selected one publication that relates microorganisms and their geological transformations (Casillas, et al., 2005). This publication was selected because it presents basic and general information, it is easy to comprehend for students of all backgrounds and it was conducted in an ecosystem that they are quite familiar with because it is located within Puerto

Rico. The paper was useful to describe some molecular tools needed to analyze the community structure of an ecosystem. For example, we discussed techniques for DNA extraction, PCR amplifications, construction of genomic libraries and the use of phylogenetic analysis to determine community structure. Once the students were familiar with microbiology and molecular concepts of the papers discussed we then concentrated on the discussion of more complicated scientific journals with techniques such as X-ray diffraction to analyze minerals, differences among minerals from biological origins and the set-up needed for experiments that simulate extraterrestrial conditions.

Course structure

The structure of the course centered around a Journal Club format in which each student was assigned a research publication. Although the selection of articles was voluntary, each publication was restricted to the eight major Geomicrobiology topics and concepts previously discussed. The first day of the course the students received an introductory lecture about topics such

Bloom's Taxonomy	Learning Skill	Example of the type of question presented
Knowledge	recall of facts	<i>Mention two bacteria species that precipitate calcium carbonate in natural environments.</i>
Comprehension	understanding and stating key concepts or main ideas	<i>Explain how the precipitation of minerals in Earth is related to the search for extraterrestrial life.</i>
Application	applying knowledge in new ways and in novel situations	<i>Which changes you need to your current methods if by microscopic observation of the samples you only found pieces of their membranes?</i>
Analysis	breaking down information into key components, finding evidence	<i>Compare the different types of crystals produced by bacteria and explain how you can differentiate them among other crystals (non biological origin) previously study in class.</i>
Synthesis	combining elements in a novel way, proposing alternate solutions	<i>Given that researchers found that at higher concentration of salts, there was a decrease in bioprecipitation by the bacteria, design an experiment to prove that this phenomenon is due to a lower number of living bacteria.</i>

Table 1. Examples of Gallery Run questions about Geomicrobiology organized according to the cognitive level at which students were engaged using Bloom's taxonomy.

as; What is Geomicrobiology? and Which are the most important biogeological transformations on our planet? The purpose of this lecture was to make sure that all students starting the course had similar knowledge about Geomicrobiology, independently of their background or year of study. At this initial lecture we also explained to the students the format to be followed in their oral presentations and discussed the main criteria to be used for their evaluations in the presentation and the course. The course evaluation was described in a syllabus given to the students on the first day of classes. The overall evaluation of the course was obtained from the presentation, with a 50% value, attendance, with a 10% value, and participation was worth 40% of the grade. Methodologies

Educational strategies

To promote an active learning environment during the Geomicrobiology course we used two main strategies: oral presentations of a recent publication in the subject followed by a Gallery Run activity or a short examination (quiz). We used quizzes to compare the student learning acquired independently by each student with the knowledge acquired during the Gallery Run. After each activity we conducted a period of discussion to clarify any remaining doubts.

Structure of oral presentations

Each student was responsible for presenting an assigned scientific journal article to the rest of

the class in an oral presentation supplemented with PowerPoint files. As shown in Figure 1, each presentation consisted of the basic elements of a common scientific article such as introduction, methodologies, results, discussion and major conclusions.

To help the students become familiarized with the main authors that wrote the publication, we requested that they looked for a picture of the facilities where the research took place as well as personal aspects of the researchers such as prior education and hobbies. Consequently, as part of their introduction, each student had to mention something particular about the first author or group leader of the publication.

They also were asked to provide background in the main topic to be covered in their presentation. Some of the students provided information about the characteristics of the Early Earth and atmospheric conditions at the stratosphere. Others answered questions such as; Which are the most resistant life forms on Earth?, What is the difference between a mineral and a rock?

Another unique feature of the presentation schedule is that in the methodologies section each student was responsible for describing the basic operation of each one of the instruments needed for the study. For example, students needed to describe how scientists were able to mimic conditions in the stratosphere using a combination of gamma and UV radiation; other students described the main characteristics of the

Criteria	4	3.5	3	2	1	Average Score
Organization	4	6	1	1	1	43/13=3.31
Content: depth and accuracy content	3	4	4	1		40/13=3.10
Research effort	3	5	4			41.5/13=3.20
Use of communication aids	6	1	4			39.5/13=3.04
Use of language; word choice	4	3	5			41.5/13=3.20
Eye contact	4	5	3			42.5/13=3.27
Audience interaction questions and answers.	5	3	4			42.5/13=3.27
Length of presentation	7	2	2		1	42/13=3.23
TOTAL AVERAGE SCORE						3.20

Table 2. Students' evaluation results for oral reports. Since many of the scores were between 3 and 4, a 3.5 column was added for tabulation purposes (4=exceptional, 3=good, 2=satisfactory, 1=needs improvement). Numbers inside table represent number of students who obtained a specific score.

materials used for the insulation modules used for *Caenorhabditis elegans* outer space trips (Szewczyk et al., 2005).

No special requests were imposed in the sections regarding the discussion of results, discussions of such findings and the presentation of the main conclusions of the work. Time for the oral presentation was limited to 20 minutes for each student. At the end of each presentation, the students had up to ten minutes to ask questions regarding the journal discussed. To encourage student participation a bonus point was added to each student that articulated a question in the discussion period. Indeed, a fundamental component of the course was the class discussions held after each oral report. We encouraged discussion in informal and formal ways. Informally, students were stimulated to ask their own questions about the material presented by their peers. Formally, they participated in a class discussion technique called Gallery Run, which is a sped-up version of the Gallery Walk (Francek, 2006). In a traditional Gallery Walk students have about 5 minutes to answer each question, but in the Gallery Run student only have a maximum of three minutes at each station.

Description of Gallery Run activities

In Gallery Run, students from different backgrounds (Biology, Microbiology and Marine Biology) were arranged into teams of three or four. Each team was provided with a different colored marker to write the answers to questions about the presentations on one piece of paper. Before the activity, the roles of a leader, recorder and reporter were assigned to group members.

The leader encouraged participation and kept the group focused on their main task, the recorder wrote group responses on paper sheets and prepared the final answer written report, and the reporter presented a summary of the group's thoughts on a question to the class. The roles were alternated between each team member throughout the course. To ensure that all students played all three roles, cards with an illustration alluding to the role were prepared and hung around each student's neck. On the back of each card the student wrote her/his name and the date she or he performed each specific role. Each week the professors in charge of the course verify that the students were indeed conducting a different role. The professors were also responsible for writing the questions based on the publication discussed that day, and ensured that the questions addressed higher-level thinking skills according to Bloom's Taxonomy (Bloom, 1956) (Table 1). Once the reporter presented their summary to the question asked, we had another period of discussion in which all ideas and concepts were discussed and doubts were clarified.

Description of quizzes

Short exams or quizzes were randomly given after some oral presentations. Quizzes consisted of a similar number of questions as those utilized in Gallery Runs; however, each student had to answer them individually. The time allowed for answering the questions was the same and they were written according to the Bloom's Taxonomy (Bloom, 1956) as were those used in the Gallery Run activity. Similar to Gallery Run activities, once the students answered the questions, they

were discussed in order to clarify any concept or idea that they had not understood.

ASSESSMENT STRATEGIES

An important aspect of the course was to determine the extent to which students met the learning goals, as well as receiving their feedback regarding the activities implemented. Consequently, we developed specific strategies based on both formative and summative assessment. Formative assessment strategies provide an immediate evidence for student learning and give the opportunity to improve it. Summative assessment, on the other hand, evaluates a particular activity to determine student's skills, knowledge or effectiveness of the activity itself (Suskie 2004).

Formative assessment

Formative assessment included all the class discussion techniques, including the two sessions of questions asked by the students after their presentations and after the Gallery Run/Quizzes. Such sessions help the students reinforce and/or clarify any doubts they had concerning the article presented that day in class. Furthermore, we used quizzes as an additional instrument to detect student understanding of the material presented in class. Three criteria were used to assess the quality of student written answers, both in Gallery Run and in quizzes: concept understanding, use of scientific language and clarity of thought.

Summative assessment

Summative assessment included the scoring rubric designed for the oral presentations and a Gallery Run questionnaire to measure student achievement and instructional effectiveness. As mentioned before, students' understanding as well as their ability to communicate science effectively in their oral presentations was assessed. Oral reports were ranked from exceptional, good, satisfactory, to needs improvement, on a scale from 4 to 1.

The Gallery Run activity was formally evaluated by the students at the end of the course using a thirteen question survey previously described for Gallery Run activities (Francek, 2007).. The survey was anonymous, non-graded and consisted of thirteen questions. Only two questions were open questions (question 1 and 2) and the rest were general observations to be evaluated by the student using a rubric (from question 3 to 13). Questions seven and eight

allowed enough space for the student to explain her/his answers.

RESULTS

The main learning goals of the Introductory Geomicrobiology course for non-geology majors were: (1) for students to present and discuss research studies about the role of microorganisms in the geological transformations of our planet as well as (2) understand the adaptations required for the establishment of extraterrestrial life. To meet both goals we used a series of educational and assessments strategies and in this section we present our major findings.

1. Oral presentations in a Journal Club format were an effective way to introduce non-geology majors to the Geomicrobiology field. All the students enrolled in the course conducted an oral presentation on an assigned publication following a Journal Club format. Each student was evaluated utilizing eight main criteria. Oral reports rubrics' global average scores were 3.20 (80%), with much of the evaluation relying between good and exceptional (Table 2). The highest scores (>3.20) were reported in student organization, audience interaction, questions and answers and maintenance of eye contact during the oral presentations. Students' explanations of concepts and theories were accurate with few errors in information, meaning that the students were able to read, understand and communicate data regarding introductory concepts in Geomicrobiology.

2. Student performance was stronger in groups than individually: Gallery Run versus Quizzes. Concept understanding, use of scientific language and clarity of thought were stronger in the answers given by the students as a team in the Gallery Run activity than those given individually in quizzes (Table 3). Total score value for all written questions in Gallery Run was 103.73, while a total of 85.07 was obtained for individually answered questions. Since all questions were always answered in the Gallery Run activity but not on quizzes, when computing these total points, the two Gallery Run synthesis questions were omitted since this type of question was not asked on quizzes.

3. Gallery Runs were more effective in promoting class participation than individual sessions of questions. To increase student participation we offered a bonus point for each question

Criteria	Gallery Runs					Quizzes				
	1	2	3	4	Total Mean Value	1	2	3	4	Total Mean Value
Concept understanding	30	32.5	36	34.7	$133.2/4=33.3$	29	28.25	29.25	26	$112.5/4=28.13$
Use of scientific language	33	39	32	39	$143/4=35.75$	32.5	27.5	29.25	27.25	$116.5/4=29.13$
Clarity of thoughts	33	39	32	34.7	$138.7/4=34.68$	29.25	25.75	28.75	27.5	$111.25/4=27.81$
Total					103.73					85.07

Table 3. Total scores values for students' written answers to questions from the Gallery Runs vs. quizzes according to the three criteria: concept understanding, use of scientific language and clarity of thought. Maximum numeric value is 117.

formulated by students after each oral presentation. Only seven students in the course asked questions and each student had an average number of 3.5 questions throughout the course. Questions were basically of two types: those in which students wished to reinforce their understanding about a particular graph or table presented; and those with which they sought a deeper explanation of a concept or theory. Even though a bonus point was granted for each question made, half of the class never asked a question. This contrasts with student behavior reported during Gallery Runs, where students were eager to talk and discuss the material.

4. Gallery Runs were the preferred class discussion technique used in the course.

A questionnaire was used to assess the relevance of Gallery Runs as a discussion technique in the course. All students agreed that the technique was easy to use, that the instructions for participating in the Gallery Run activity were clear, and that it really encouraged collaboration among the students (more than with other class discussion techniques). They also commented that through Gallery Run discussions they gained a more complete understanding of the topics presented (Table 4)..

Interestingly, when the students compared Gallery Runs to quizzes, they highlighted that the technique provided a deeper understanding of the journal assigned in class due to the opportunity to work collaboratively, learn from their peers and share ideas (Table 4).. When they answered questions individually their understanding was not as complete. One student mentioned on the

questionnaire that only when quizzes were discussed by the professor during the question session was he able to understand the material to the degree he did with Gallery Run activities.

Summarizing other answers from the questionnaire, all students (100%) indicated that they would like to participate in another course utilizing Gallery Run activities in the future. The Gallery Run activity was favored by the students due to its multiple advantages such as its ease of use, its quite dynamic nature, its allowing for collaborative work, and that it provides an opportunity for more complete discussion as well as a deeper understanding of the publication assigned.

Eighty-five percent of the students agreed that the wording of Gallery Run questions was clear, while 15% was neutral (question 9). Regarding the timing for discussing each topic at the learning stations (question 10), 69% agreed that they had enough time to discuss each topic at learning stations but 23% was neutral and 8% disagreed.

DISCUSSION

We have described the objectives, structure and assessment of a new undergraduate course designed to introduce non-geology majors into the field of Geomicrobiology. One of the achievements of the course was to expose students to major topics and concepts in Geomicrobiology throughout different activities which were far from the traditional lecturing teaching style. Because we were aware that none of our students have a background in Geology or Geochemistry, we needed to make sure that they were not only exposed to the new information but

Questions	Response
1. What did you like about Gallery Run?	<ul style="list-style-type: none"> • Provides for group discussion • Participation in different roles • It is dynamic • Provides for a deeper understanding of the topic discussed
2. What did you dislike about Gallery Run?	Lack of time to discuss each topic at the learning stations To inform orally
3. The directions for the Gallery Run were clear. I know what to do to successfully complete a Gallery Run.	100% Agree
4. We worked more collaboratively than with usual class discussion techniques.	100% Agree
5. During the Gallery Run, all group members participated.	100% Agree
6. During the Gallery Run, my group listened respectfully to one another.	100% Agree
7. I gained a better understanding of the topic using Gallery Run than through the oral report alone. Explain your answer.	92% Agree; 8% Neutral <ul style="list-style-type: none"> • With Gallery Run ones gets a better understanding of the topic because answers to questions are discussed with peers • Gallery Run is effective in clarify any doubt about the topic • Gallery Run is a dynamic discussion technique and because of that it is more easy to recall the information as with listening to an oral report alone
8. I gained a better understanding of the topic using Gallery Run than when answering the individual set of questions alone. Explain your answer.	100% Agree With Gallery Run ones gets the opportunity to share and discuss ideas with peers, helping to gain a better understanding of the topic than when you have to deal with it by yourself
9. The wording of Gallery Run questions was clear.	85% Agree; 15% Neutral
10. I felt we had enough time to discuss each topic at learning stations.	69% Agree; 23% Neutral; 8% Disagree
11. Gallery Run was easy to use.	100% Agree
12. My overall experience with Gallery Run was satisfactory.	100% Agree
13. I would like to participate in another Gallery Run.	100% Agree

Table 4. Student responses to questionnaire for Gallery Run evaluations.

also that had the opportunity to process it. To engage students and enhance their learning experience we promoted, from day one, an active learning environment.

The first way to actively involve the students in the course was for them to present oral reports on a current scientific journal article about Geomicrobiology. The oral presentations encouraged students to read, present and discuss recent Geomicrobiology research regarding eight major concepts in the field. Our results showed that the students acquired the necessarily skills and basic knowledge for presenting an oral report in the Geomicrobiology science field, our main learning goal. The fact that our students' oral reports rubric scores ranged between good and

exceptional is the best indicator (Table 2). Students felt quite comfortable with their presentations, were able to maintain eye contact and answered most of the questions. Nevertheless, in some instances we observed that students lack the knowledge to explain molecular techniques that are relevant to the field. For example, in the presentation of the article Community Structure, Geochemical Characteristics and Mineralogy of a Hypersaline Microbial Mat, Cabo Rojo, PR, the student failed to include an explanation of the T-RLFP technique used to assess changes in the microbial community structure in their presentation, as well as not mentioning the mineral composition of the mats (Casillas-Martinez et al. 2005). Fortunately,

the discussion of the articles by the professors at the end of the course provided an opportunity to supplement information omitted in students' presentations and to correct such difficulties.

Another way we promoted active learning during the course was to encourage both non-structured and structured discussions. According to Bonwell and Eison (1991, in-class discussion is one of the most effective strategies for promoting active learning. Indeed, the assessment of our structured discussions using the Gallery Run technique revealed superior student participation and improved the quality and quantity of their answers to written questions when compared to quizzes. Student answers to written questions provided us with direct evidence of their ability to understand information about Geomicrobiology through three different criteria: concept understanding, use of scientific language and clarity of thought. As previously reported students did better answering questions when they work in teams rather than individually, resulting in more complete and coherent answers (Table 3). This was also true regardless the cognitive level that the question involved (knowledge, comprehension, application, analysis or synthesis). For example, when an analysis-type question on a quiz asked students to make inferences about the considerations for successfully conducting an experiment based on the discussion of a journal article describing how *Caenorhabditis elegans* survived atmospheric breakup of STS-107, Space Shuttle Columbia (Szewczyk et al. 2005), students showed difficulty arriving at a logical answer individually. Similar types of experimental approaches were questioned when discussing prior journals during Gallery Runs and the students had no problem in responding successfully. Indeed an improvement was observed when students answered analysis-type of questions as groups. We have previously determined that students working in groups in Gallery Runs possess a more complete understanding of the material as a direct result of the active discussions of the students on the team than when they worked on their own (Ríos-Velázquez et al. 2007). Student's evaluations obtained through the questionnaire and the evaluation of the course activities concur with such findings (Table 4).

The lack of an educational setting in other courses where higher-order thinking tasks are routinely assigned and assessed to encourage cognitive development could be one of the reasons why students present difficulty when

dealing with these types of questions on their own (McConnell et al. 2005). Since discussion is superior to lecture for promoting higher-order thinking skills involving analysis, evaluation and synthesis (Kelly 2004 and Johnson and Mighten 2005), a discussion technique such as Gallery Run could be implemented as a regular activity in other science courses to help students develop such skills.

Another advantage of using Gallery Runs is the multiplicity of roles (leaders, reporters and/or recorders) in which the students are able to develop both oral and written skills. As students needed to participate as reporters in each group at least one time, they develop skills such as correct technical writing of relevant scientific parameters (i.e., units for total radiation, pressure, how to report cell death during a mission or total bacterial counts after the vessel returns). In the role of speakers, even the more introverted students were encouraged to participate, a task that helps their self-confidence increase. One of the most important outcomes of the Gallery Runs was that the students were able to work as multidisciplinary teams. Even though students were from different backgrounds (Biology, Marine Science and Microbiology) they were able to effectively communicate and share knowledge from each field in order to answer the questions. The capacity to work on multidisciplinary teams is very important in Geomicrobiology, where teamwork of professionals from different backgrounds is virtually mandatory (Ríos-Velázquez, 2007).

As a result of our assessment, we can conclude that most of our non-geology major students learned basic Geomicrobiology concepts even though our University does not possess a Geology Course in its curricula. Such a limitation can then be overcome if an active learning environment in the classroom is implemented using oral reports and discussions as main class activities. As previously reported, class discussions not only contributed to keep the excitement in the class but also promoted scientific literacy, which was an important goal we needed to accomplish (McConnell et al. 2003 and Burbach et al. 2004). Our course provided an effective environment for learning Geomicrobiology, especially for non-geology majors with very little background in the subject.

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