To what extent are higher-order thinking questions posed during the Mission to Mars program?

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Abstract
This paper explores the role of questioning as a key pedagogic strategy to engaging learners in higher orders thinking and presents the results from observational research undertaken at the Victorian Space Science Education Centre. The research focused on investigating questioning strategies used to facilitate the inquiry-based Mission to Mars program that aims to engage and immerse students in a technology rich and sensory stimulating environment based on real-life scenarios and hands-on approach to science learning within the context of space. The current paper highlights the importance of questioning in science education and presents VSSEC with some valuable feedback and recommendations for improvement.

Keywords: questioning strategies, higher orders thinking, science education, VSSEC, inquiry-based learning

Introduction

There is a general consensus that science education is fundamental to developing citizens who can become 'effective explorers of the world' (Gregson, 2012, p. 7) . Connecting students with science, regardless of whether they wanted to pursue it as a career or not, is central to education in order to cultivate investigative, creative, path-finding and opportunity-seizing risk takers who are unafraid to undertake the journey of curiosity and wonder about the unknown. Critically, this highlights the role of questioning and inquiry in science as a way of interrogating the world through observation and critical and creative thinking.

There has been a gradual and continuing decline in student engagement with the sciences (Fensham, 2009); there are mounting concerns that the poor understanding and negative views on science and technology amongst the general public is impacting on the number of secondary students choosing science as a career (Kessels, Rau, & Hannover, 2006; Narayan, Park, Peker, & Suh, 2013). This presents problems to the future of science, scientific research and communication (Lunn & Noble, 2008).

Stocklmayer, Rennie, and Gilbert (2010) advocate informal science settings play a major role as enablers of science, with often more significant contributions to science learning than in-class science experiences. This paper presents educational research undertaken at the Victorian Space Science Education Centre (VSSEC) that focused on investigating questioning strategies used to facilitate the centre's signature Mission to Mars program. The current paper highlights the importance of questioning to learning, and education in general, and presents VSSEC with some valuable feedback and recommendations for improvement.

The importance of questioning

Curiosity is a part of the hard-wiring of the brain (Willis, 2008); questions lie at the heart of all human communication and information exchange — they come naturally to all of us. Through questioning we satisfy a critical human need — connection. In classrooms where the climate encourages and respects questions, there is no end to the 'connection' possibilities (Peery, Patrick, & Moore, 2013) — questions build relationships and language interactions between the teacher and students and among the students, promoting empowered learning (Gregson, 2012).

Skillful questioning plays a major role in knowledge construction and as an enabler of critical and creative thinking, inherent to science and the innovation process (Landau, 2007). Questions lead us to wonder, build memory and imagination, focus attention, create emotional involvement, hook the learning and present opportunities to effectively examine the nature of both teaching and learning (Fusco, 2012). Effective questioning invokes engagement; it drives learners to clarify their thinking and deepen their understanding (Rothstein & Santana, 2011); it can be used to introduce new ideas, elicit existing knowledge, and encourage a powerful dialogue (Gregson, 2012); it allows learners to make new connections to concepts and ideas (Peery et al., 2013); it encourages learners to reflect on their ideas and to compare their perceptions with those of others (Fusco, 2012); it also builds the confidence of students' own questioning as they model their teachers (Pagliaro, 2011).

Artful questioning may be the most powerful tool teachers have in their instructional toolkits; it is the key to educational change and transformation (Fusco, 2012; Pagliaro, 2011; Peery et al., 2013). Research has consistently shown that effective questioning is one of the teaching strategies that have the greatest impact on student achievement, and that higher-level questions have a significant impact on enhancing student comprehension (Danielson, 2007, 2008; Good, 1996; Hattie, 2009, 2012; Marzano, Pickering, & Pollock, 2001; Redfield & Rousseau, 1981; Wang, Haertel, & Walberg, 1993). Therefore, considerable attention should be given to developing questioning skills of both novice and expert teachers.

Teachers ask literally hundreds of questions a day, as has been documented by numerous studies over the past few decades (Leven & Long, 1981; Pollock, 2007) — we cannot underestimate/overemphasise they their impact. Llewellyn (2013) has called questions 'the language of inquiry' (p. 127); Peery et al. (2013) argue that there is no other discipline that relies on questions more heavily than science. Hence, if teachers want empowered learners leaving their science classrooms at the end of their time together, there needs to be a powerful dialogue between teachers and students and between students, as they acquire and manipulate knowledge, and both teachers and students must ask effective questions and deeply listen to the answers.

Context and background

The Victorian Space Science Education Centre (VSSEC) offers high quality science programs within the context of space that endeavour to foster inquiry-based learning and engage learners in a technology rich and sensory stimulating environment based on real-life scenarios and hands-on activities (VSSEC, 2013). Constructivist approaches and inquiry-based models of learning, such as those run by VSSEC, engage the learner through cognitive conflict and puzzlement, cultivate understanding through interactions with environment, create knowledge through social negotiation, and through evaluation of viability of the individual's understanding (Churchill et al. 2011).

The Mission to Mars program supports learners in developing ownership of the problem or task at hand by allowing them to take on the role of a research scientist-astronaut, exploring the surface of Mars, or a mission controller who oversees the safety and progress of the astronauts and is responsible for the overall success of the mission. Students work in two groups of six. One group of students sets out to the surface of Mars with specific instructions to collect soil and rock samples, to conduct thermo-analysis and measure seismic activity. To simulate a real-life scenario, students are dressed in space suits, equipped with infrared cameras and metal detectors, collect samples and raw data, which then needs to be further analysed in the laboratory. The mission is supervised and monitored by mission controllers who use computer software specific to their role (e.g. weather and environmental condition tracking, astronaut health status, systems control) to process and analyse data and communicate via audiovisual links with astronauts on the surface. Three, specially trained, in-house educators facilitate the program, usually university students, to serve as role models and inspire interest in science as a career.

Mission to Mars is a full day program (six hours); this allows the students to switch roles. The program is typically supported by a six-lesson pre-mission training that seeks to develop content knowledge and understanding necessary for its successful completion. During our observation, the program was being undertaken by a group of Italian Year 11 students with good conversational English abilities. However, these students have not had the opportunity to complete the pre-mission training and hence their understanding of specific planetary science required by the program would have been compromised and may thus pose limitations to this study.

Research aims

My research has focused on investigating questioning strategies of VCCEC educators. Through this research I have gained a better understanding of the importance of questioning in the science classroom and anticipate that the results will be of benefit to VSSEC as an evaluation tool of the quality of questioning techniques utilised during the Mission to Mars program.

My research was guided by the following question:

To *what extent were higher order thinking questions posed by VSSEC educator during the Mission to Mars program to guide and support student learning*?

Further sub-questions helped to guide my data analysis:

1. To what extent does questioning during the program align with Bloom's Taxonomy? Do the questions asked by the educator target higher orders thinking?
2. What types of questions are posed by the educator? To what extent does questioning change as students' progress through the program?
3. What types of question stems are used by the educator?

4. To what extend did the students respond to questions posed? What types of questions does the program elicit in its participants? Does the instructor allow sufficient think/wait time?

Methodology, method and tools

Observation was the prescribed method for conducting research VSSEC. O'Toole and Beckett (2013) advocate observation as a method allows unobtrusive investigation whilst participants are aware that research is taking place. Furthermore, observational research does not typically require an ethics approval.

Close observation was directed at the questioning strategies taking place in the Mission Control (MC) room and quantitative data was obtained during the preparatory period i.e. review of planetary science content knowledge and technical aspects of the mission; and the post-mission debrief. In this instance, both group 1 and group 2 successively undertook the same program and were guided by the same facilitator. Further observations and data collection was made during the practical laboratory session in the afternoon that saw both groups of students combined, guided by the same facilitator as the MC sessions. No observations were made on Mars surface (for logistical reasons) or in the MC room during the mission progress (due to difficulties in obtaining meaningful/objective data). Research presented in this paper has focused on observing one VSSEC educator only, and involved a group of ESL students, and thus cannot be generalised.

In order to verify observations and data obtained, triangulation process, commonly used to corroborate evidence from at least two other independent angles (O'Toole & Beckett, 2013), was employed during two separate meetings with a colleague who also observed questioning strategies at VSSEC. Furthermore, all raw data was crosschecked, and has shown consistency of findings across the board. As such, the attempt to triangulate data has afforded this research a degree of credibility and validity, and overall trustworthiness.

Research design involved a template for recording of the questioning process — Chuck Wiederhold's Question Matrix (Weiderhold & Kagan, 1995) was appropriated alongside revised Bloom's Taxonomy (Anderson, Krathwohl, & Bloom, 2001) (see Appendix) to suit the research question. Each time a question was posed by the instructor/participant it was aptly coded within the matrix against a specific question stem and level of cognitive complexity it was aimed at; it was coded as one of three question types: literal, inferential, and metacognitive. Questions supported by elaboration cues, think/wait time, questions answered by students (individually and collectively), as well as questions that the facilitator answered himself without seeking students' input were duly marked. Both participant and instructor questions were coded separately; each stage of the mission was coded on a separate sheet. This approach was successful in obtaining a range of reliable data. Furthermore, the research is easily repeatable utilising the data collection template, and hence it can be afforded a degree of reliability.

Presentation of results and findings

To what extent does questioning during the program align with Bloom's Taxonomy? Do the questions asked by the educator target higher orders thinking?

Science instruction can be wonderfully engaging when in the hands of effective teachers and supported by critical questioning and dialogue; it can lead to students' becoming sharper in their reasoning and, as time goes on, result in a deeper conceptual understanding of science content (Gregson, 2012).

Figure 1 (below) shows the most commonly used taxonomy representing the complexity of cognitive operations — Bloom's Taxonomy — applied to analyse the range, and hence complexity and effectiveness of questioning during the Mission to Mars program. Results indicate that 70% of total questions posed by the VSSEC educator are lower order thinking questions. The questioning concentrated primarily on information recall and clarification of understanding with regard to instructional strategies; 30% of questions targeted higher orders thinking. According to Peery et al. (2013), in science, periods of questioning directed by the teacher may be frustrating because getting the 'right' answer often takes priority due to time constraints and need to cover the curriculum; nonetheless, deep conceptual knowledge, not regurgitation of facts, should be the primary objective in every case.

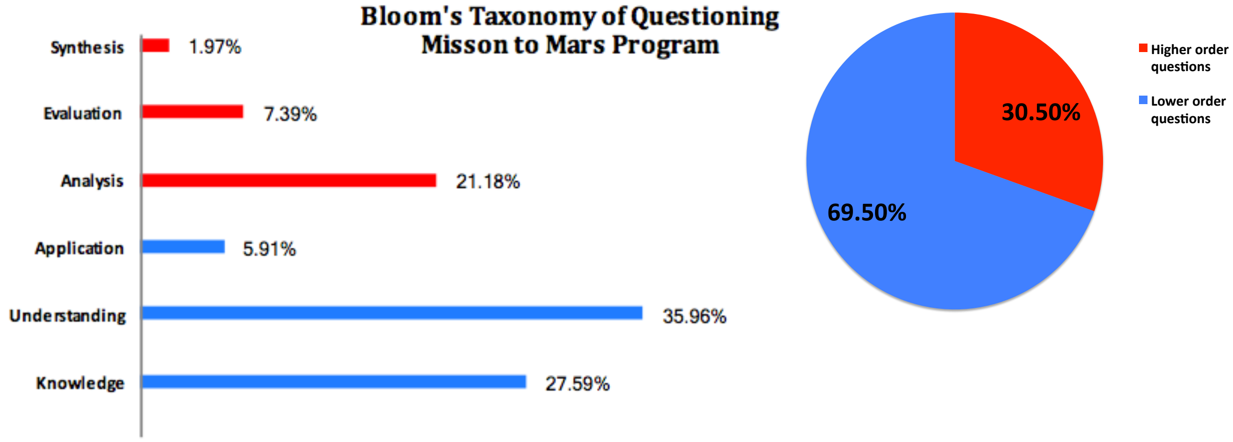


Figure 1: Questions posed by the Mission to Mars facilitator coded against the Bloom's Taxonomy of cognitive complexity.

These findings are consistent with Hattie's (2009) research on 144 factors that influence student learning. He has conducted the most comprehensive meta-analysis of these factors to date and, concluded that 60% of questions that teachers ask about the content of the lesson are recall level, and another 20% of questions are procedural or behavioural. Hattie (2009) notes that most teachers' questions, both verbal and written, relate only to surface knowledge, and in some studies recall-level questions comprised 80% of the questions asked (p. 182). Hence, as Peery et al. (2013) stress, the reality is simple, 'educators must break the pattern of pelting students with low-level questions' (p. 16) — powerful, higher order questioning techniques are essential if students are to master the content and skills necessary for success in academia, the workplace and in life.

What types of questions are posed by the educator? To what extent does questioning change as students progress through the program?

Fusco (2012) suggests that effective questioning begins with assessing question context and purpose, the former refers to the relationship between the question and the topic at hand or main concepts being developed, and considers the background knowledge of students and how it connects to other questions; the latter refers to the reasons a question is asked — engage students participation, initiate discussion on a topic issue or pose a problem, or to evaluate students understanding and identify misconceptions.

Along with questions purpose and context, Fusco (2012) suggests there are three basic types of questions: *literal* (closed) (require memorisation and recitation; have only one right answer); *inferential* (open) (anticipate responses not directly stated of specified); *metacognitive* (encourage reflection on thinking and learning).

Undoubtedly, each questions type has its value and should be used appropriately. Research has shown that 30% of total questions asked during Mission to Mars were literal/closed questions (Figure 2). These were aimed at eliciting recall information, requested factual knowledge or sought to bring forth information that was explicitly stated. Fusco (2012) states these types of questions are useful for establishing factual foundations on which to base inferences and can serve as a warm up and to build inferential questions. Although closed questions have their place in learning, research observations have noted that many questions posed during the program could have been better framed to engage more critical thinking e.g. instead of 'did you find opal on Mars?' the question could have been posed as 'what rocks did you find on Mars?'

Marzano (2010) advocates that 'making inferences is the foundation to many of the higher-level thinking processes that we want students to use more effectively in the 21st century (p. 81). The majority (63%) of questions posed by the VSSEC educator were inferential or open-ended questions (Figure 2). Fusco (2012) stipulates that inferential questions demand more critical thinking as they encourage students to elaborate, clarify, summarise, justify and qualify — allowing them to go beyond facts and interpret or manipulate the information in some way in order to construct an appropriate response and develop their own lines of reasoning.

Research has found that although many inferential questions were asked during Mission to Mars, many were directed at checking whether students understood what they were doing e.g. 'what is your role in Mission Control?' These questions could have been better supported by further explorations of e.g. 'why is your role important to the mission?' Furthermore, many questions were not afforded sufficient think/wait time before proceeding to the next question and often ended up a missed opportunity.

Metacognition is an important component of being able to identify both what and how we are learning (Willis, 2008). Metacognitive questions build students' cognitive skills by allowing them to become more aware of their own thinking needs and processes (Peery et al., 2013). Hattie (2012) has ranked metacognitive strategies as 14th (out of 144) most effective strategies to use with students. 7% of all questions asked during Mission to Mars were aimed at metacognition (Figure 2). This number indicates lack of reflection, which as Shön (1995) states is paramount, because it allows us to understand what has 'been implicit in our actions, that which is surface and which needs to be criticised, restructured, and embodied in further action (p. 50).

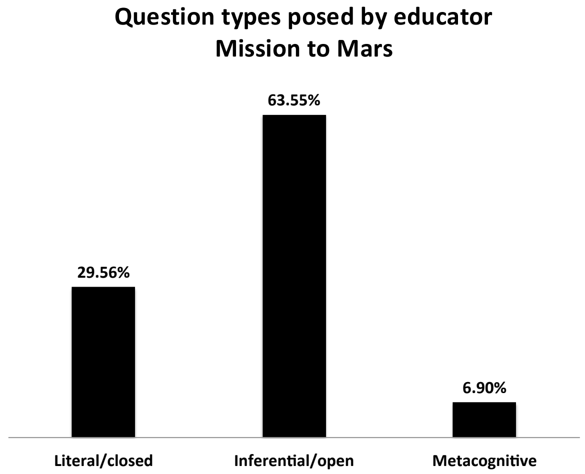


Figure 2: Breakdown of questions posed by VCCEC educator, by question type — literal, inferential, and metacognitive.

Furthermore, it has been found that the overall questioning pattern dropped dramatically throughout the program, group 1 deserving the most attention in terms of questioning (Figure 3). 5% of all questions were asked during the final practical laboratory session (that followed on from data and sample collection) and the subsequent debrief; this stage would have benefited from a more extensive analytical and evaluative approach to summarise and reflect on the day's learning.

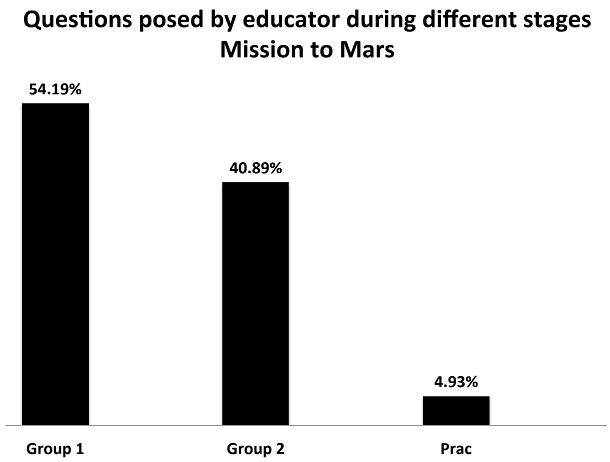


Figure 3: Breakdown of questions posed by VSSEC educator, by stage of program — AM: Group 1 (MC room), Group 2 (MC room); PM: practical laboratory session (all students combined).

The full breakdown of question types posed by VSSEC educator during the Mission to Mars is presented in the table below:

Table 1: Breakdown of questions posed by VSSEC educator, by stage and type; supported by elaboration cues.

Q's posed by educator	Group 1		Group 2		Prac		Total
Question Type	Mission Control	Mission Debrief	Mission Control	Mission Debrief	Intro	Debrief	
Literal/closed	24	6	25		1	4	60
Inferential/open	58	12	49	5		5	129
Metacognitive	9	1	4				14
Per stage of program	91	19	78	5	1	9	
Total	**110**		**83**		**10**		**203**
*Elaboration cues	23		14				37

What types of questions stems are used by the educator?

Peery et al. (2013) suggest powerful questions immediately engender deep, diverse, creative or metacognitive thinking. Although in some cases lower-level, prerequisite questions, may precede the more powerful questions, it is imperative that inferential and analytic questions are used as often as possible. These types of questions move beyond 'who', what', and 'when/where' to 'why' and 'how' (Marzano et al., 2001). Research results (Figure 4) indicate low frequency use of these types of question and present an area for improvement.

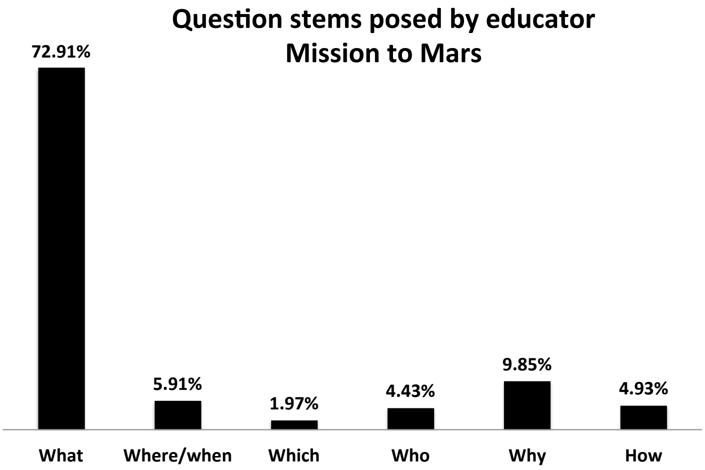


Figure 4: Breakdown of question stems used by VSSEC educator during the program

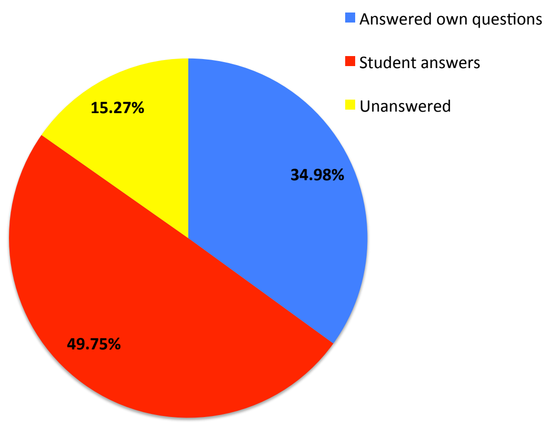
To what extend did the students respond to questions posed? What types of questions does the program elicit in its participants? Does the instructor allow sufficient think/wait time?

Hattie (2012) emphasises the importance of student talk vs. teacher talk — he calls for teachers to engage in a dialogue, not a monologue. Peery et al. (2013) advocate powerful questioning is reciprocal and collaborative; the person asking does not do so in isolation, but does so in order to engage another's mind and/or emotions; a curious mind may obviously create endless questions — but the most powerful questions are created and answered in partnerships with other curious minds.

Research has shown that throughout the session students asked a total of 11 questions and answered 50% of total questions asked. 35% of questions were rhetorical – the educator would pose questions or ask a string of questions that he would answer himself; 15% questions were left unanswered (Table 2). We have identified this area as critical in need of improvement.

Table 2: Breakdown of questions: posed by VSSEC educator — by stage, including wait/think time given; questions posed by students; questions answered by students (individual and collective), questions self-answered by VSSEC educator, and questions that remained unanswered.

	Group 1	Group 2	Prac	Total questions	
Questions asked					
By educator	110	83	10	203	
Think/wait time given		3		3	
By students	10	1		11	
Questions answered					
By individual students	42	27	6	75	
By students collectively Y/N answer	16	10		26	
Total questions answered/unanswered					Percentage of total questions answered
By students	58	37	6	101	49.75% (74.26% individual; 25.74% collective Y/N)
Answered own questions (educator)	44	26	1	71	34.98%
Remained unanswered	8	20	3	31	15.27%



Furthermore, it would be beneficial to give more sufficient think/wait time, both when questions are posed and when students are asked 'do you have any questions?' Peery et al. (2013) suggest in effective question-posing teachers are not afraid of silence. Rowe (1986) suggests providing at least three full seconds of wait time, not seeking immediate answers. She stresses the importance of letting students struggle cognitively, allowing them to process what has been said before answering. This is particularly crucial when it comes to ESL students as the processing time from one language to another is multiplied (Sun, 2012). Sufficient wait time, in this instance – ESL students, would also indicate differentiated and individualised approach to delivering the program.

Wait time also allows teachers to plan ahead for the questions they will pose next and anticipate those that students might ask — pre-planned questions are necessary for emphasising the habits of mind and to deepen conceptual understanding (Peery et al., 2013); ultimately, planning can divert the focus on application of higher level cognitive questions to help better facilitate learning. The bottom line is that while 'telling' may seem more efficient, 'asking' and interacting are where the relationship of learning between teacher and student is build — where there is powerful questioning there is a powerful and productive community of learners.

Discussion

Informal science programs, such as Mission to Mars, allow the culmination of scientific knowledge and understanding by facilitating their application and evaluation through productive collaboration and meaningful problem solving tasks that encourage students to look more closely and think more deeply, in authentic environments that could not be created in a standard classroom; they have the capacity to foster deep inquiry related to scientific processes (such as observation, hypothesising, predicting, measuring, analysing data), and by combining these processes, making links with scientific knowledge, scientific reasoning, and critical thinking, simultaneously provide opportunities that allow learners to recognise that the fixed set and sequence of steps, known as the scientific method, is only a partial guideline and does not represent accurately the inquiry approach adopted by real scientists. Research evidence suggests that inquiry approaches produce more higher-order learning outcomes than recipe style experiments (Gregson, 2012); however, our observations at VSSEC indicate that despite being promoted as inquiry-based, the program was information and procedural-focused and lacked elements of 'true' inquiry in its questioning facilitation approach.

We should be mindful that students do not necessarily learn because they show up in class —students' actions must reflect more than a symbolic compliance, and include behaviours such as active listening and freely offering ideas in class discussions (Marzano, 2007). Hattie (2012) notes when students own and discuss their learning, they become self-regulated learners — 'when student can… self-regulate their learning, they can use feedback more effectively to reduce discrepancies between where they are in their learning and the desired outcomes or successes of their learning. Such feedback, usually in the form of reflective or probing questions, can guide the learner on 'how' and 'why' in selecting or employing task- and process-level knowledge and strategies (p. 120). Furthermore, teachers who are excited about learning have students who are excited as well, because it is easy to share excitement when we have it in abundance (Marzano, 2007).

This research concludes in recommendation for improvement by suggesting the implementation of a procedure known as the 'questioning cycle', as outlined by Fusco (2012), in which the teacher plans questions, asks questions, allows wait time, listens to student responses, assesses student responses, follows up on those responses with another question, and re-plans based on students' subsequent responses. Furthermore, utilising Chuck Wiederhold's Question Matrix is recommended to sharpen questioning strategies of VSSEC educators to broaden the range of question stems utilised and to target areas of more cognitive complexity to ensure the inquiry nature of the program remains supported.

Conclusion

Fusco (2012); Peery et al. (2013) contend that the more intentional a teacher is about using questions in the classroom, the greater the chance that students will learn to become fluent in both cognitive and conative (motivational) skills. Effectively generated questions allow students to build explanations and interpretations, reason with evidence, make connections, consider alternatives, form conclusions, uncover complexity and go below the surface of things; ultimately, they capture the heart and enable a sense of wonder.

Practical work in science offers great opportunities for student generated questions and true inquiry; it should however not be an instructional exercise during which students are merely following directions, nor should there be a superfluous afterthought that is only transiently related to the instructional sequence of content.

Despite areas in need of improvement, it is clear that the Mission to Mars program is carefully thought out and designed with a single focus in mind — attainment and cultivation of science skills relevant to real life, carried out in stimulating high-tech multimodal learning environments, while anchoring all learning activities to a larger task or a problem. I have found the program particularly exciting — what better way to show young learners the missions real astronauts or space scientists engage in than by immersing them in challenging and complex problem-solving tasks and projects that ignite their wonder and curiosity in earth and space sciences. It is my hope that this program is the beginning of something bigger — the learners' future interest and perhaps a real passion for and dedication to further study and a career in earth and space sciences.

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