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Inquiry-based science education as multiple outcome interdisciplinary research and learning (MOIRL)

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Abstract

The article provides the basis for a model of inquiry-based science education in which K-12 teachers' and pupils' engage in authentic science experiences as participants of a scientific research project, which we refer to as Multiple Outcome Interdisciplinary Research and Learning (MOIRL). We provide the basis for the model for inquiry based science education (IBSE) by first describing how the model came about through our 10 years of research on how people learn to do science in research groups. We then turn to the literature on the relationship among scientific inquiry, inquiry learning and MOIRL. As our case studies of MOIRL projects show, by being participants along with scientists and their graduate/undergraduate students in authentic scientific research, school pupils learn how to do science and gain a better understanding of scientific concepts. Productive disciplinary engagement can be fostered with learning environments that are problematic in the sense that they encourage students to ask and seek answers to intellectual questions. By incorporating as many stakeholders and outcomes as possible, the likelihood increases of pupils' learning of science concepts and processes. In addition, the incorporation of multiple stakeholders and outcomes provides pupils with a view of the many authentic ways that science and scientific inquiry is connected to the world outside of school, which increases the likelihood that they study more science and aspire to scientific careers. Finally, the MOIRL projects provide teachers with the opportunity to engage in scientific research, which can better prepare them to teach science as inquiry and through the use of inquiry methods.

Key words: *authentic inquiry, productive disciplinary engagement, stakeholders, school-university partnerships*

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Introduction

The purpose of this article is to provide the basis for a model for inquiry-based science education in which K-12 teachers' and pupils' engage in authentic science experiences as participants of a scientific research project, which we refer to as Multiple Outcome Interdisciplinary Research and Learning (MOIRL). We provide the basis by first describing how the model came about through our 10 years of research on how people learn to do science in research groups. We then turn to the literature on the relationship among scientific inquiry, inquiry learning, and MOIRL. Throughout the article we draw upon examples of MOIRL projects.

In the MOIRL model, a range of stakeholders engage in varied research and learning activities leading to multiple outcomes (see Figure 1). While the model includes a wide range of possible stakeholders, for the projects described in this article the stakeholders are pupils (4-12); teachers and education researchers; scientists, engineers and graduate students; and community members (Chapman, Feldman, Alshehri, Özalp, & Vernaza-Hernández, 2013; Feldman, Chapman, Özalp, Vernaza-Hernández, & Alshehri, 2012; Vernaza-Hernández, Feldman, Chapman, Alshehri, & Özalp, 2013). In what we envision as its full implementation, MOIRL would combine university-based academic interdisciplinary research (Aboelela et al., 2007; Lattuca, 2002) with action research (Altrichter, Feldman, Posch, & Somekh, 2007) and community-based participatory research (O'Fallon & Dearry, 2002) in a way that is best described as “transdisciplinary” (Pohl & Hadorn, 2008). Learning would occur in all spheres of interactions among stakeholders: formal K-16 and graduate education; informal education settings; and community activities. Learning would also occur as stakeholders engage in scientific, educational, community and business activities through their legitimate peripheral participation (Lave & Wenger, 1991) in research communities of practice (Feldman, Divoll, & Rogan-Klyve, 2009; Wenger, 1998).

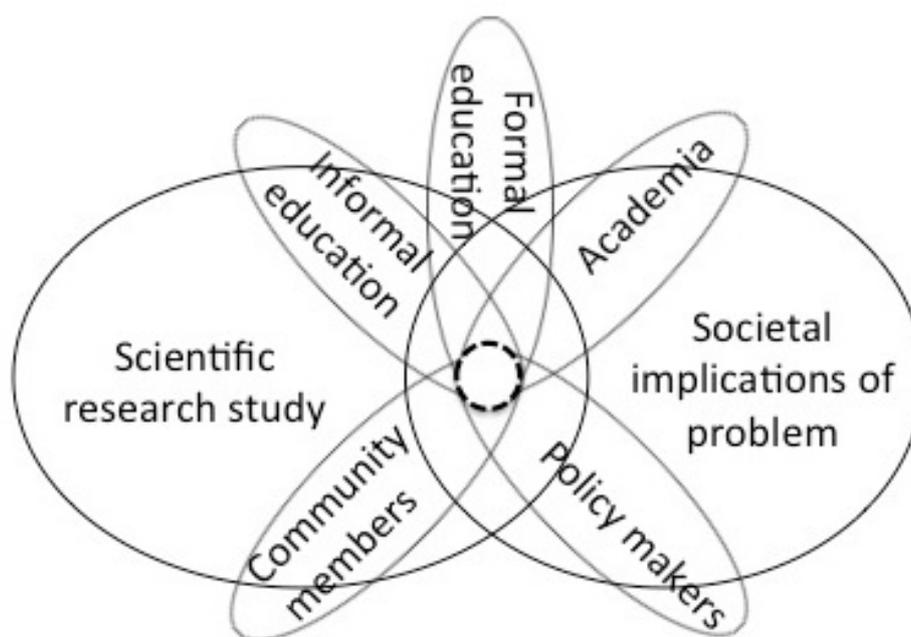


Figure 1. Multiple Outcome Interdisciplinary Research and Learning (MOIRL) model highlighting the intersection of multiple stakeholders

While the multiple stakeholders have their own desired outcomes, as science educators who are interested in formal K-12 education, we are most interested in the way that teachers and pupils participate in MOIRL projects and how they are affected by that participation. For example, one of our projects, which we call the Camuy caves project, was a collaboration between Prof. Soler, a professor of geology at a large research-intensive university in the southern United States (the University), and teachers and pupils in three schools in Puerto Rico. Prof. Soler is a speleologist, specializing in the relationship between cave formations and climate change. His work with the teachers and pupils in Puerto Rico was funded by the National Science Foundation (NSF) as part of a grant on climate change education. The Camuy cave project began with the teachers teaching the pupils about caves, karst, and cave formations using materials developed by Prof. Soler. Next, they made a field trip to the Camuy cave during which Prof. Soler explained to the pupils how scientists obtain information about climate change through the study of the formations that they were seeing in the cave. He also showed the students data loggers designed to measure temperature and humidity that were installed inside and outside the cave, explained how they work, and how the data is used in his research. The humidity and temperature data were collected for six months. The data were given to the pupils who analyzed it using spreadsheets. They then prepared posters of their results that are intended to be put on display at the Camuy cave visitor center (Vernaza-Hernández et al., 2013). Vernaza-Hernández found that the pupils gained knowledge about climate change science, caves and karst, and how they are related. She also found that the pupils developed the research skills associated with the doing of science. All of her findings were statistically significant.

Before we turn to the development of the model, we believe that it is necessary to connect it explicitly with the field of inquiry based science education (IBSE). The term inquiry is used in multiple ways in the science education literature, including the process that scientists use to study the natural world, a way of describing a learning process, and pedagogical methods and materials (Bybee, 2002; Center for Inquiry-Based Learning, 2007; Crawford, 2007; Layman, 1996; National Research Council, 2000). In some of our MOIRL projects (Chapman et al., 2013; Vernaza-Hernández et al., 2013) the teachers and pupils engage in scientific research practices that are connected to the scientist's research focus. As a result, the teacher and pupils are inquiring into the natural world in the first sense of the meaning of inquiry. That is, they are engaged in the doing of science to help generate knowledge and understanding of the natural world. In all of our MOIRL projects the pupils, as well as the teachers, are learning science through inquiry. As our research studies of MOIRL projects are showing, by being participants along with scientists and their students in authentic scientific research, they learn how to do science and gain a better understanding of scientific concepts. Finally, because, as we see when we observe the MOIRL model implemented in classrooms, the teachers, along with the scientist and graduate students from his or her research group, are teaching the pupils both the content and processes of science through the research experience, they are engaged in inquiry pedagogy (e.g., Chapman et al., 2013; Vernaza-Hernández et al., 2013).

Development of the MOIRL model

Learning to do research

Our development of the MOIRL project began with our work as part of an interdisciplinary science project funded by the National Science Foundation (NSF) (Feldman et al., 2009; Feldman, Divoll, & Rogan-Klyve, in press). The project, which included a geologist, two environmental engineers, and a microbiologist, was a study of the natural remediation of acid mine drainage (AMD) at an abandoned pyrite mine (Yuretich, Ergas, Ahlfeld, Nuesslein, &

Feldman, 2004). A fifth principal investigator (one of the authors of this article) is a science education professor. His primary role in this study was to examine the effects of teachers' participation as researchers in the project. As the study unfolded, it became clear that it was important to gain a better understanding of how people learn to do research as part of a research group. This led to the development of the following model of how people learn to do research.

The education of the research group members (typically graduate and undergraduate students) occurs as part of an apprenticeship (Lave & Wenger, 1991). The apprenticeship takes place in research groups. Students have different roles and status in the research groups. Their status is dependent upon whether they are undergraduates, master's degree candidates, or doctoral students. They can be in the role of novice researcher, proficient technician, or knowledge producer. Depending on their status in the research group, they can develop from novice researcher to proficient technician, to knowledge producer. The members of the research group including the professor and other students facilitate the development of the students along the continuum of roles (Feldman et al., 2009).

STEM Research Academies for Young Scientists

This model of learning to be a researcher was developed through observations and interviews of university students and faculty. In 2006, the NSF solicited proposals for its Academies for Young Scientists program. In response to this a proposal was submitted to NSF for the STEM (Science, Technology, Engineering and Mathematics) Research Academies for Young Scientists (STEM RAYS). In STEM RAYS, upper elementary and middle schools pupils and teachers were connected with ongoing interdisciplinary environmental research programs in the region, providing them with authentic science experiences and interactions with scientists, engineers, and college and graduate students. Pupils and teachers collected and analyzed data to be used by the scientists and engineers in their research projects. STEM RAYS was developed using the above model for how people learn to do research. Four to five teachers worked with each scientist and became members of his or her research group. Each teacher ran an after-school science club with 10-15 pupils, who, by extension, became part of the research groups.

The multiple stakeholders in STEM RAYS had their own outcomes. NSF wanted to increase pupil learning of science, and interest in STEM careers in settings outside of the regular school day. The STEM RAYS PIs shared NSF's goals, as well as a strong interest in improving science teaching and learning in the region. Teachers were interested in participating in authentic research, learning more science, and finding ways to incorporate their new knowledge into their teaching. The scientists primarily saw this as an opportunity to do outreach, but for some it was a way to explore how they could make use of the data generated by the pupils. The pupils were excited about the opportunity to engage in authentic science and to meet real scientists (Feldman & Pirog, 2011).

The stormwater project

A look back at the way in which we described the MOIRL model above indicates that while STEM RAYS had some of the types of interactions among stakeholders hoped for in MOIRL, there is little connection with the world outside of schools and universities. This is true even though the STEM RAYS scientists did their research in different aspects of environmental science. What led to the completion of the MOIRL model was our opportunity to work with Prof. Canter, who is a professor of environmental engineering at the University. One of her

areas of research is the movement of non-source pollutants in urban areas by stormwater into the Gulf of Mexico. She received a grant from the US Environmental Protection Agency (EPA) to work with schools and community members to reduce the amount of pollutants contributed by citizens through actions such as fertilizing their lawns. We came to know her and her work through a project that we call the stormwater pond project (Feldman et al., 2012). The site of project was an urban middle school (Ghent MS) in a large metropolitan area in the southern United States.

The focus of Prof. Canter's efforts was a stormwater retention pond located across the street from Ghent MS. As with many of the ponds in the poorer neighborhoods of the city it had been neglected for many years. It was surrounded by a chain-link fence and was strewn with trash. There were few plantings and the water was high in nutrients that led to the growth of invasive aquatic plants and algae. Prof. Canter worked with a local community group that received funds to improve the pond. She recruited an architecture professor from the University to help with the design. As a result, at this time the pond has become a resource for the community with a walking trail and platforms to view the pond life.

Prof. Canter and her graduate students have also been working with teachers and pupils at Ghent MS. They have developed a water quality curriculum that is being used in the school in which the pupils perform tests of the pond water and keep records of plants and animals in the pond. In addition, the pupils provided text and photos for an educational kiosk located at the ponds. Finally, as we noted above, Prof. Canter and her graduate students do research on the movement of pollutants through stormwater and use the pond as a site for their research.

Prof. Canter has multiple objectives for the stormwater pond project. First, it is part of her ongoing research into ways to mitigate the transport of pollutants through stormwater. This is also an area of research that interests her graduate students. They are enrolled in an environmental engineering program seeking either a master's degree or doctorate. Both degrees require original research, and because they are under the direction of Prof. Canter, their research is subsumed within her overall research program. Second, in addition to being a researcher she is an educator, and the stormwater project is a site for her students' learning. Third, she is concerned with the improvement of the community in which she does her research. As a result she collaborates with the community group that oversees the ways that city money is used for neighborhood improvement. Finally, she wants to improve the educational experience of K-12 pupils in the community, which is why she works with teachers.

It should be clear from the above that Prof. Canter expects multiple outcomes from her involvement in the stormwater project. But the other stakeholders also have multiple outcomes. For example, Ms. Hamal, the teacher who collaborates with Prof. Canter, has outcomes that she would like to achieve for her pupils and for herself. She sees the stormwater project as an opportunity for her middle school pupils to engage in scientific research, and to interact with a real scientist and graduate students, and a way to augment her curriculum to improve the pupils' learning of science. It is also an opportunity for her to work with a scientist and to connect with the university. This can lead to her professional development including the learning of science. She also has the opportunity to develop curriculum that will be disseminated to other teachers in the school district and made available through an engineering education website. This same type of analysis can be done for the different stakeholder groups that would show how the one project provides them with the opportunity to work toward the outcomes that are particular to them. However, in the same way that community involvement was missing from the STEM RAYS projects, the

stormwater project is missing pupil or teacher involvement in Prof. Canter's ongoing research. That said, neither STEM RAYS nor the stormwater project is an example of full implementations of the MOIRL model. However, we hope that we have demonstrated the importance of these projects in the development of the model.

Theoretical basis for the MOIRL Model

We now turn to a more theoretical analysis of the relationship between MOIRL and inquiry based science education (IBSE). In this section we examine three different ways that the literature looks at the activities of science and how they support the MOIRL model as a form of IBSE.

Authentic science

Brown, Collins and Duguid (1989) describe authentic activities as the "ordinary practices of the culture" by which "meanings and purposes are socially constructed through negotiations among present and past members" (1989, p. 34). In science these activities include "asking questions, planning and conducting investigations, drawing conclusions, revising theories, and communicating results" (Lee & Songer, 2003, p. 923). Therefore, authentic science inquiry refers to the research that real scientists do when they do science (Chinn & Malhotra, 2002). Chinn and Malhotra provide an outline of the cognitive processes that scientists engage in when they do authentic inquiry. These include below:

- Generating research questions
- Designing studies
- Making observations
- Explaining results
- Developing theories
- Studying research reports

Clearly each of these processes is multifaceted. For example, the design of studies includes selecting variables, planning procedures, controlling variables, and planning measures. Similarly, the explanation of results requires a wide range of skills and knowledge to transform observations from raw data into the forms that can analyzed, to be self-critical of ones methods, to be able to reason through complex chains of variables, to make generalizations, and to be able to use a variety of reasoning strategies (Chinn & Malhotra, 2002). Unfortunately, Chinn and Malhotra argue conclusively that little of this happens in what they call "simple inquiry tasks", which is the primary form of inquiry enacted in school settings.

In the MOIRL model, pupils engage in inquiry as part of their involvement in the scientist's ongoing research. This can be seen in one of our current projects, which we call 'the algae project'. The partner scientist is a professor of environmental engineering at the University. One of her projects is a study focused on the growth of algae in wastewater as a biofuel source. Teachers and pupils at an urban low socio-economic status high school constructed smaller scale models of the bioreactors that the scientist uses in her laboratory. The pupils are culturing the algae in a greenhouse located on the campus of the high school. Over the course of 4-6 weeks, students are monitoring algae growth conditions, including total solids, pH, temperature, and natural light conditions in an effort to determine optimal conditions in which algae grow. Pupil groups are responsible for maintaining a lab notebook of their methods and data. The algae are being assayed for lipid concentration to determine which growing

conditions are most suitable for harvesting algae as a biofuel source. Because lipid analysis involved the use of hazardous chemicals, properly trained graduate students are conducting this part of the study at the University.

The algae study is being done in two cycles. In the first, the pupils are given a research question about algae growth for which they collect and analyze data. This provides the pupils with the opportunity to learn the skills needed to do the research. In the second cycle, the pupils, in consultation with their teacher, the partner scientist, and the graduate students, identify research questions that support the university-based research. Although the quality of the pupils' data is not as reliable as that of the graduate students, the partner scientist has told us that their research provides her with qualitative data that enables her and her students to test out the fruitfulness of various strategies for increasing the algae growth rates on wastewater. For example, they have looked at how variations in gas flow rates affect algal growth. Our preliminary analysis of data from our study of the algae project suggests that the pupils engage in most, if not all of the cognitive processes that Chinn and Malhotra (2002) say scientists engage in when they do authentic inquiry.

Productive disciplinary engagement

A second way of examining the MOIRL model is to use the concept of productive disciplinary engagement developed by Engle and Conant (2002). According to Engle and Conant, students are experiencing productive disciplinary engagement if 1) they exhibit behaviors that are indicative of engagement (e.g., they make substantive contributions in discussions that relate to comments of other students; they exhibit body language that suggests paying attention; they are emotional about their involvement; and they spontaneously re-engage with the topic over a sustained period of time); 2) their engagement consists of participating in the discourse (Gee, 1999) of the discipline; 3) and their engagement is productive in the sense that there is evidence that they are making intellectual progress (Engle & Conant, 2002). These are just the types of behaviors that we expect of pupils when they are engaged in scientific inquiry, and map nicely on to Chinn and Malhotra' (2002) list of cognitive processes.

Engle and Conant (2002) argue that productive disciplinary engagement can be fostered with learning environments that are problematizing in the sense that they encourage students to ask and seek answers to intellectual questions. The learning environments should also provide students with the authority to be active agents in the problem solving process, by having a stake in the results. Engle and Conant also argue that it is important for students to be held accountable to disciplinary norms such as what is recognized as good practice and what counts as knowledge. Finally, the learning environments should have sufficient and relevant resources to enable all of this to happen.

We believe that when the MOIRL model is enacted in classrooms, it provides a learning environment that fosters productive disciplinary engagement of teachers and pupils. Because the pupils engage in authentic science in partnership with scientists and their research groups, the MOIRL classroom environment encourages pupils to ask and answer intellectual questions. This is evident in the algae project where pupils are encouraged to construct hypotheses about the factors that affect algal growth, develop research questions based on those hypotheses, and then test them in the school laboratory setting. The partner scientist and her students make it clear to the pupils that their investigations have a purpose that goes beyond their classroom and can not only contribute to the partner scientist's research but also eventually the actual production of biofuels. Therefore, the pupils are active agents in the

problem solving process and develop an ownership of the outcomes. In addition, because the partner scientist and her students expect to use the pupils' data, the pupils are taught what the good practice of science looks like and what needs to be done for their results to count as knowledge.

Engle and Conant (2002) also argue that there need to be sufficient and relevant resources to transform a classroom into a site for productive disciplinary engagement. Clearly not all schools have the resources that are required to enact projects like the stormwater project or the algae project. As we noted above, the EPA funded Prof. Canter's work with Ghent Middle School. The algae product is being funded as part of a large NSF grant on climate change education. While these external funds support the purchase of materials and supplies, and provide small stipends for the teachers, neither of the professors receives any direct compensation from these projects. What this suggests is that we cannot expect the MOIRL model to be widely duplicated given the current state of school finances; demands put on teachers time; and the need to find scientists who are both willing to put in the time to work with teachers and pupils, and have research projects that can be done to some extent in a school setting.

Views of science

Finally, we turn to Matthew Weinstein's analysis of the relationship between school science and science as culture. Weinstein begins by noting that two of the goals of science education are to teach pupils how science is done and the results of scientific activity (Weinstein, 2008). Using literature from social studies of science, he suggests that science in schools can be understood as different framings like those that are achieved through the use of a zoom lens on a camera. The narrowest view is what he calls "science as investigation." He argues that this is what is seen most often as inquiry in classrooms. It is inquiry presented and done as context-free sets of methods to solve problems. The novice researcher is immersed in this view of science. As one widens the view, either by zooming out or pulling back the camera, we see "science as work." In this view, science is seen to include a wide array of activities in addition to investigations, such as grant writing, publications, and conferences. Pulling back even further, one can see science as work being influenced by economics. This science as "enterprise" includes the factors affect the funding of science, such as the potential for profit. From the widest view we can see "science as culture": science embedded in the social spheres of culture, politics, and history (Weinstein, 2008).

One of the intents of MOIRL is to provide this zooming out experience for pupils and their science teachers. It should be clear that their involvement with scientists in authentic science provides the pupils and teachers with the opportunity to go beyond school science inquiry activities to experience science as work. While the pupils may not see all the intricacies of grant writing and publications, they can be made aware of their participation in grant-funded activities, and make presentations of their research efforts to their peers or at conferences. Participation in MOIRL projects can also open a window to science as enterprise. For this to happen, the scientists and their students, as well as other stakeholders, would need to make explicit that the research, and most likely the partnership, is happening because of outside funding sources. Because the MOIRL model includes an explicit connection to stakeholders outside of academia, pupils see how, for example, the politics of city government come into play when research is situated in schools and communities.

Conclusion

In this article we have described, given examples of, and provided some theoretical bases for a new model for inquiry-based science education. As we noted above, we have not yet had the opportunity to put into place a full of implementation of the model as we envision it. As we reflect on MOIRL, and look again at Figure 1, we wonder if we are somewhat too ambitious or optimistic about the possibilities of a full implementation. At this time, we have had MOIRL projects that include university-based researchers and schoolteachers and pupils with strong connections to the academic research, but little connection to other possible stakeholders such as community groups, politicians, or business (e.g., Chapman et al., 2013; Feldman & Pirog, 2011; Vernaza- Hernández et al., 2013). We have also had projects in which there is a strong connection to stakeholders outside of academia including the stormwater project (Feldman et al., 2012) and two others that we have not described that focus on the relationships between climate change and phenology, and climate change and sea level rise. It may be the case that full implementation is too complex a goal to achieve, and that the MOIRL model can best serve science educators as a model toward which we can strive. It also can serve as a reminder to us that inquiry-based science education can include a wide range of stakeholders with differing objectives, and can be situated in multiple sites that go beyond formal and informal science education institutions. We also believe that by incorporating as many stakeholders and outcomes as possible, it increases the likelihood that it will increase pupils' learning of science concepts and processes. In addition, the incorporation of multiple stakeholders and outcomes provides pupils with a view of the many authentic ways that science and scientific inquiry is connected to the world outside of school, which increases the likelihood that they study more science and aspire to scientific careers. Finally, the MOIRL projects provide the teachers with the opportunity to engage in scientific research, which can better prepare them to teach science as inquiry and through the use of inquiry methods.

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