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RESIDENT SCIENTISTS' INSTRUCTIONAL PRACTICE AND THEIR PERCEIVED BENEFITS AND DIFFICULTIES OF INQUIRY IN SCHOOLS

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Abstract. *This study determined the nature of the laboratory activities undertaken by Resident Scientists in high schools through a science education outreach project. This study also attempted to determine Resident Scientists' perceived benefits and difficulties of students doing inquiry science activities in schools. A sample comprised eight Resident Scientists at a medium-sized University in Midwest of the USA. Resident Scientists were serving in a University-School partnership project funded by the National Science Foundation (NSF) GK-12 program. Data was collected through a questionnaire. Results show that the reported laboratory activities were at guided and verification inquiry levels and nothing at structured and open inquiry levels. Resident Scientists recognized the important role of inquiry, benefits and difficulties for implementing inquiry in schools. Their perceived difficulties for inquiry in schools represent barriers for open inquiry in science classrooms. These findings have some implications for science learning, teaching and teacher education.*

Key words: *Resident Scientist, inquiry, teaching, science, benefit, difficult.*

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Introduction

Inquiry-based science teaching has been accentuated in science education reforms and standards (American Association for the Advancement of Science [AAAS], 1989; National Research Council [NRC], 1996). According to these science education reforms and standards, inquiry is both a teaching approach and learning goal. As a teaching approach inquiry involves students learning how to ask questions, proposing explanations, testing those explanations against current scientific knowledge, and sharing their ideas with others (Haefner, 2004; Kang, Orgill & Crippen, 2008), learning to question their own observations, as well as those made by others (Moore, 1993; Huber, 2001) and dealing with frustrations of experimental error, missing data and uncontrolled variables (Okebukola, 1988). On the other hand, inquiries as a learning goal include abilities to do inquiry and understanding of the foundations of inquiry (NRC, 1996).

Beyond science education reforms and standards and science curriculum materials science teachers are expected to develop scientific inquiry skills among students by implementing science laboratory activities that address different levels of inquiry such as: *Verification, Structured, Guided and Open-ended* (Tafoya, Sunal & Knecht, 1980; Hegarty-Hazel, 1986). Verification is the lowest and open-ended is the highest level of inquiry. Students must also be exposed to inquiry skills for *planning and conducting experiments, analyzing and interpreting data, and applying techniques to new situations* (Tamir & Luneta, 1981). In order for science teachers to implement these inquiry levels and skills in their classrooms they must have good understanding of inquiry and teach science by inquiry. As such, studies have examined teachers' conceptions of inquiry (Haefner, 2004; Kang, Orgill & Crippen, 2008) use of inquiry

activities in science classrooms (Schulz & Mandzuk, 2005; Jones & Eick, 2007; Buck, Macintyre-Latta, & Leslie-Pelecky, 2007; Lotter, Harwood & Bonner, 2007), challenges for implementing inquiry lessons (Costenson & Lawson, 1986; Roehrig, 2004; Wee, Shepardson, Fast & Harbor, 2007), the effect of inquiry activities on students' enjoyment and achievement (Kahle & Damnjanovic, 1994), and inquiry levels addressed by teachers in schools (Staer, Goodrum & Hackling, 1998). Other studies have examined college science instructors' and scientists' views of inquiry (Brown, Abell, Demir & Schmidt, 2006; Hardwood, Reiff & Philipson, 2002). In general, these studies report that most teachers do not have complete understanding of inquiry. As such, inquiry-based instruction has been difficult for some teachers to accept and implement in their classrooms (Tamir, 1989; Constenson & Lason, 1986; Roehrig, 2004). For example, Kang *et al*. (2008) found that teachers associated inquiry with students merely following experimental procedures. Such view only reflects the low level inquiry. Staer et al. (1998) also reported that high school teachers were generally not implementing open inquiry activities in science lessons even though they were aware of the multiple benefits of inquiry in high school classrooms. Teachers cited three difficulties: time constraints, classroom management problems, and demands for more equipment. Similarly, Brown, Bell, Demir and Schmidt (2006) found that college science faculty members had full and open inquiry view but they believed that inquiry was more appropriate for upper level science students than for introductory or non science majors.

It is evident in the literature that studies on inquiry have mainly focused on pre-service and in-service teachers, except for the two studies that examined college science faculty views of classroom inquiry (Brown et al., 2006; Hardwood et al., 2002). To date, no study has explored scientists' instructional practice in K-12 classrooms and their perceived benefits and difficulties of students doing inquiry science activities in schools. Yet, many scientists are working with teachers and students in schools through science education outreach programs. Therefore, more attention to scientists' instructional practice and their perceived benefits and difficulties for inquiry in schools is warranted, as this may contribute to better science teaching and learning and teacher education. The purpose of this study, therefore, was to determine the nature of the laboratory activities undertaken by Resident Scientists (Masters and PhD students) in schools through a science education outreach project. This study also attempted to determine Resident Scientists' perceived benefits and difficulties of students doing inquiry science activities in schools.Two research questions guided this study: (a) what levels of inquiry do Resident Scientists report they are using in science activities in schools? (b) What do the Resident Scientists perceive to be the benefits and difficulties for students doing inquiry activities in schools?

Context of the Study

This study was conducted in the National Science Foundation (NSF) funded GK-12 Project at a medium-sized university (20,000 students) in the Midwest of the USA. The main goal of the project is to improve science teaching and learning in local schools by sending Resident Scientists (MSc and PhD students) to schools to help teachers with subject matter knowledge and teaching. Resident Scientists were training to be scientists and not to be certified as teachers. In addition to their involvement in the outreach project, Resident Scientists conduct scientific research for their degree programs and professional development. The project started in 2006, and it is in the third year of its five-year plan. The project is following the NSF model of putting scientists in classrooms in schools to help teachers with subject matter knowledge and teaching. This model is based on the premise that Resident Scientists can be good content resources to teachers and their students. The project recruits and supports Resident Scientists through fellowships. Resident Scientists spend 15 hours per week in schools preparing and teaching science lessons and working with students on scientific projects. Resident Scientists also act as role models in classrooms to foster positive attitude towards science among students. Since its inception, the project has trained and supported more than twelve Resident Scientists from Departments of Plant Biology, Geology, Zoology, and Molecular Biology within the University. A Resident Scientist is only allowed to be in the project for a maximum period of two years. At the beginning of the school year new Resident Scientists are matched with teachers. Later in the year, as Resident Scientists establish stronger working relationships with teachers in participating schools, matching with additional teachers occurs. In some

of the settings, they work with a single teacher. In other cases, a pair of Resident Scientists works with a single teacher or with a pair of teachers.

Methodology of Research

This research study employed a qualitative methodology that involved collecting qualitative data through a questionnaire. The descriptions of the sample, data collection instrument and procedures, analysis frameworks and procedures have been provided below.

Sample

A sample comprised eight Resident Scientists (six females and two males) whose profiles are shown in Table 1 below.

Table 1. Profiles of Resident Scientists.

Name	Sex	Science discipline	Degree program	Duration in the project (months)	School	Subjects taught in schools	Grades taught	No. of students
RS1	F	Plant Biology	MSc	9	HHS	Chemistry & Food science	9-12	60
RS2	F	Plant Biology	PhD	18	CCHS	Chemistry & Environmental science	10-12	65
RS3	F	Plant Biology	PhD	9	RBHS	Biology & Anatomy	9-12	84
RS4	F	Plant Biology	PhD	9	CHS	Biology	10-12	120
RS5	M	Plant Biology	PhD	9	CHS	Biology, Anatomy & physiology	10-12	120
RS6	F	Geology	MSc	9	CHS	Biology & physics	9-10	130
RS7	M	Geology	MSc	18	MHS	Earth science & Chemistry	9-12	75
RS8	F	Molecular Biology	PhD	18	CCHS	Biology	10	62

Note: RS stands for Resident Scientist

Table 1 shows that five Resident Scientists were in Plant Biology doctoral program, two were in Geology masters' degree program, and one was in Molecular Biology masters' degree program. The average age of the group was 26 years. None of the Resident Scientists was a trained teacher or had school teaching experience prior to joining the project. However, some Resident Scientists had one or less than a year teaching experience as teaching assistants in undergraduate science courses.

Data was collected through a modified questionnaire developed by Staer et al. (1998). Originally, the questionnaire was developed to collect data on openness to inquiry from high school teachers in Australia. More items on demographic and laboratory format were added. The first section included questions about Resident Scientists' gender, duration in the program, degree program, name of the school, number of classes and students, and subjects and grade levels they taught in schools. The second section asked Resident Scientists to report on the last science lesson they had taught in schools. Questions asked about the grade level, the topic, and whether the problem, materials, procedure, and

the answers to the problem were given by Resident Scientists or decided by the students. Resident Scientists were asked if the reported lesson was typical of the science lessons they taught in schools. The third section had open-ended questions on what Resident Scientists'perceived as benefits and difficulties of students doing inquiry in science classrooms.

Analysis Frameworks and Procedures

A framework and procedure developed by Tafoya, Sunal and Knecht (1980) was used to analyze Resident Scientists' reported laboratory activities for inquiry levels. The framework has four inquiry levels: *Confirmation/verification, Structured, Guided, and Open*. Confirmation inquiry level activities require students to verify concepts through a known answer and given procedure that the students follow. Structured inquiry level activities present students with a problem in which they do not know the results, but they are given a procedure to follow in order to complete the activity. Guided inquiry level activities provide the student only with a problem to investigate. Students are given a chance to determine the procedure to use and the data to collect. Open inquiry level activities allow students to formulate problems, hypotheses and the procedure for collecting data for interpretation and drawing conclusions. Participants' responses on reported laboratory activities were read and matched with the characteristics of inquiry levels outlined in the framework. The Resident Scientists' responses on benefits and difficulties of inquiry were also coded and put in categories. Two science educators independently analyzed the data using the procedures described above. Then, the two met to compare and discuss the findings that emerged from the analyses. Minor differences that emerged in their findings were resolved through sustained discussions and a group analysis on the aspects that needed to be re-examined.

Results of Research

Inquiry Levels in the Reported Laboratory Activities

Table 2 below shows that four of the eight reported laboratory activities were at guided inquiry level. This implies that Resident Scientists prescribed the problem, materials but the procedure was partly chosen by the students and the answers were not given to the students before the laboratory activity. However, one Resident Scientist (RS2) reported that in a chemical bonding laboratory activity students had some autonomy to choose some materials for the experiment.

Table 2. Inquiry Levels in the Reported Lab Activities.

Name	Lab activity	Subject	Problem		Materials			Procedure			Answer		Inquiry level
			Given	Open	Given	Partly Open	Open	Given	Partly Open	Open	Given	Open	
RS1	Osmosis	Biology	X		X				X			X	3
RS2	Bonding	Chemistry	X			X			X			X	3
RS3	Carlotta Island	Biology	X		X				X		X		1
RS4	Yeast Cells	Biology	X		X				X		X		1
RS5	Graphs	Physics	X		X				X			X	3
RS6	Genetic	Biology	X		X				X			X	3
RS7	GMOs	Biology	X		X				X		X		1
RS8	Biomes	Biology	X		X				X		X		1

RS stands for Resident Scientist; Inquiry levels 1,2,3,4 are Verification, Structured, Guided and Open, respectively.

The other four reported laboratory activities were at verification level of inquiry where Resident Scientists prescribed the problems, materials, procedures and the expected answers. Although students partly participated in developing procedures in some reported laboratory activities, they were not offered more opportunities to engage in higher order of inquiry.

When asked how representative the reported laboratory activities were of the science lessons they taught in schools, five Resident Scientists rated them *very well*, two Resident Scientists rated them *satisfactory* and one Resident Scientist rated her laboratory activity *poor*. This implies that most reported laboratory activities were typical of the lessons Resident Scientists taught in schools. In terms of inquiry levels found in the reported laboratory activities, there was no difference among Resident Scientists from the three science disciplines, and between those who had been in the project for more than a year and those who had been in the project for less than a year.

Benefits and Difficulties of Open Inquiry

Resident Scientists recognized that this type of inquiry facilitates: *interest; enjoyment; curiosity; positive attitude towards science; ownership; greater understanding of concepts; development of advanced process skills; appreciation; opportunity to do advanced experiments; confidence; and better transition to independent projects at college level.* For example, one Resident Scientist wrote "Students feel more connected to their work because they have put in time and effort to plan their experiments". Another Resident Scientist described students' reactions to open-inquiry in her classroom "when a beaker with water, a plastic pipette, and a piece of wax paper were given but no instructions were specified for them… soon students started playing with the water on the wax paper and discovered some of the cool properties of water. They really enjoyed the exercise and …students could remember the properties of water a week later."

On the other hand, Resident Scientists perceived the following difficulties for students doing open inquiry in schools: *unworkable experimental plans; lack of process skills; lack of confidence; time constraints; larger class sizes; unable to direct their own learning; classroom management; students prefer to be told what to do rather than think; and more equipment required for different experiments.* For example, one Resident Scientist said that "in some cases students' experimental plans might not be feasible and not enough to facilitate learning of the main concepts". Most Resident Scientists also stated that a significant number of students become confused and frustrated if they are not given clear and specific instructions to follow in a laboratory activity. As a result, "some students do not engage in this kind of laboratory activity and find this freedom as an excuse to act out or just distract other students". In addition, "students get nervous when they have to plan and carry out an experiment when less time is given". Class management can be a serious problem in larger classes. For example, one Resident Scientist said "it is difficult to keep track of what is going on in larger classes when students are doing lots of different lab activities". Another Resident Scientist observed that "cleaning up can be more difficult as more equipment is taken out and used and there is greater probability that the equipment won't end up in its original location".

Benefits and Difficulties of Guided Inquiry

Resident Scientists said that this level of inquiry facilitates the following: *creativity; interest, some ownership; some freedom to choose variables; less confusion; classroom management; and process skills*. Some of the benefits are the same as those they perceived for open inquiry. One Resident Scientist said that "when students have some autonomy to define experimental procedure they can find out that there are different ways to answer the problem posed". In addition, "students have the opportunity to propose creative ideas to solve the problem or respond to the questions". Another Resident Scientist said that "by having some autonomy, students are allowed to be creative and think for themselves". One other Resident scientist said "students also do not become entirely discouraged because they have some guidance as to how to complete the lab exercise". They also said that "if the lesson is partly directed, teachers can have more freedom to move around the class to help those who are struggling to develop

their experimental procedures". "Teachers can address students' individual needs at group or individual level, and be more certain that they will focus their attention on main concepts in the activity". In addition, "the teacher has more control over the equipment that is being used, cleaned, and returned to shelves. "Students still are responsible for applying thought to a question and predicting a result rather than just following pre-determined steps".

However, Resident Scientists recognized the following difficulties for students doing guided inquiry science activities: *lack of skills for experimental designs and procedures; time constraints; anxiety; lack of interest and effort; and students are used being instructed*. For example one Resident Scientist wrote that "students have no interest in science and struggles to do labs". Another Resident Scientist said that "when students are not allowed to participate in the procedural determination, they do not have much opportunity to analyze the steps needed to solve the problem. As a result, students do not critically address questions or problems". Another Resident Scientist also observed that "students often rush through the lab questions and don't give them as much thought as they would if they had to develop their own questions. Students also ignore portions of the instructions, and thus often don't understand the lab or the results at all".

Benefits and Difficulties of Verification Inquiry

Resident scientists perceived the following benefits for students doing verification inquiry science activities: *less confusion and frustration; development of science process skills; confidence enhancement; less time consuming; preparing themselves for advanced labs; classroom management; and easy to grade lab reports*. For example one Resident Scientist said "class management is easier when all students know the answer before the lab activity and have to follow the same procedures". Another Resident Scientist also said, "it is easy to identify students that are struggling to do the lab activity". For others, "grading is easier because the procedure and answer are the same for everybody". Most Resident Scientists also mentioned that their students preferred to be told what to do and how to do it rather than create their own problems and procedures. One resident scientist affirmed "if it is the first time students are being exposed to science activities, there are some benefits for providing a problem and detailed procedures for the lab activity". In such a situation, "there is generally less confusion and frustration among students when the answer and procedures are given before the lab activity". According to Resident Scientists, "when specific steps are given for students to verify the answer their confidence increase and they focus on the lab activity".

On the other hand, Resident Scientists identified some difficulties for this type of inquiry such as: *lack of ownership; boring; lack of opportunity to answer own questions; difficult to keep class interested; students tend to speed through the labs just to get them done; and mainly tests procedural understanding rather than re-enforcing scientific inquiry.* One Resident Scientist said "students go through steps to finish the experiment without much critical thinking and understanding". According to Resident scientists, students' learning is seriously affected when they are engaged in verification activities because such activity poses little challenge to students. Another Resident Scientist stated "such activities provide them with little opportunities for retention and comprehension of the concepts." Another Resident Scientist commented that "it is hard for the teacher to keep the entire class interested in such labs, especially if these are only types of labs students do in every science lessons."

Discussion

The reported laboratory activities were at guided and verification inquiry levels and nothing at structured and open inquiry levels. The advantages of low level inquiry activities are: students gain procedural knowledge and manipulative skills which they can later apply in open-ended activities (Woolnough & Allsop, 1985); students can complete the investigations within the allowed time (Soyibo, 1998); easier for teachers to grade students' reports, especially that standard marking keys are used (Mumba, Chabalengula, & Wise, 2007); motivates students to learn science (Brown et al., 2006). However, low inquiry levels mainly stimulate students' thinking about the procedure and results of the experiments

(Tafoya, Sunal & Knecht, 1980; Soyibo, 1998). As such, in the reported laboratory activities students were not offered opportunities for more open investigation work and development of high-order scientific inquiry skills that are emphasized in science education reforms and standards (AAAS, 1989; NRC, 1996). Therefore, there is a gulf between the call for more open inquiry in science education reforms and standards and Resident Scientists' instructional practice in the reported laboratory activities.

Some of the benefits of students doing inquiry science activities in schools perceived by Resident Scientists are similar to those reported in previous studies. For example, Tamir & Luneta (1981) and Mumba, Chabalengula & Wise (2007) also reported that the use of inquiry activities promotes scientific inquiry and problem-solving skills among students; enhance students' interest in science, and reflects science as it is practiced by scientists. Similarly, Hodson (1990) and Watts (1991) observed that students develop sense of pride and ownership in their experiments that leads to greater understanding of the content studied and deep appreciation of what they have done. Resident Scientists' perceived benefits of inquiry science teaching are also consistent with the rhetoric on inquiry in science education reforms and standards (AAAS, 1989; NRC, 1996). On the other hand, Resident Scientists' perceived difficulties for implementing inquiry in science classrooms were student-based and logistical in nature. Such, difficulties represent barriers for open inquiry in science classrooms. Therefore, these difficulties must be addressed if more open inquiry is to be implemented in schools by Resident Scientists.

These results suggest some implications for science teaching and learning and teacher professional development. For example, a potential overriding constraint to implementing different levels of inquiry in schools among Resident Scientists maybe due to lack of knowledge about levels of inquiry and inquiry-based science teaching. Similarly, Harwood et al (2002) reported that scientists acknowledged the important role of inquiry in science classroom but were not aware of certain features of inquiry for science classrooms. Research also shows that teachers' understanding of inquiry and confidence in using inquiry methods improves through developing and presenting inquiry lessons, observing other teachers' inquiry lessons, participating as students in workshop inquiry activities, and engaging in scientific inquiry (Haefner, 2004 & Lotter et al., 2007). Therefore, Resident Scientist could benefit from a training program in which a broader view of inquiry is discussed. During the training program Resident Scientists could be taught how to design lessons that encompass the features of inquiry with varying degrees of openness and amounts of inquiry. Research also shows that without exemplar inquiry curriculum resources and professional development for teachers little will change in the way teachers view inquiry (Keys & Bryan, 2001). Therefore, it would be necessary for Resident Scientists to have access to field-tested examples of inquiry lessons that are practical given the constraints of doing inquiry in schools. Such curriculum resources should provide a concrete basis for demonstrating science activities at different inquiry levels for different grade levels. Thus, Resident Scientists can start to build an understanding of how different levels of inquiry can be structured and implemented in science classrooms.

Conclusion

Although Resident Scientists recognized the role of inquiry in science classroom, their reported laboratory activities reflected lower order inquiry. Resident Scientists' perceived difficulties for implementing inquiry in science classrooms were mainly student-based and logistical in nature. Such difficulties must be addressed if more open inquiry is to be implemented in schools by Resident Scientists.

While the extent to which open inquiry experiments should be used in science classrooms in schools may be questioned considering the limited time for science laboratory activities, it should be an integral component of science instruction. On the other hand, when the various demands of open inquiry tasks are taken into consideration, it seems unrealistic to expect students to perform many open inquiry activities in science lessons. However, the responsibility to include different levels of inquiry activities in schools rests with Resident Scientists and partner teachers.

As such, we recommend that classroom observations should be undertaken to find out the extent to which the levels of inquiry and inquiry skills are addressed by Resident Scientists in science classrooms in schools.

Finally, the findings of this study have significant implications for science teaching and learning,

teacher education, and professional development. For example, knowing inquiry levels Resident Scientists' are addressing in schools is important to those who are involved in science education outreach programs and teacher education. This study does not only contribute to the existing literature on instructional practice by scientists but also leads to understanding the conditions under which scientists perceive to be conducive for different levels of inquiry in K-12 science classrooms.

Note: The version of this paper presented at NARST 2010 annual meeting was work in progress and the sole purpose of the presentation was to get feedback from experts.

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