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Whose Science Is It Anyway? Models of Science According to Chemistry Students, Faculty, and Teachers

This study describes data collected from undergraduate chemistry majors, high school chemistry teachers, and chemistry faculty in an effort to better understand how models and conceptions of scientific inquiry might change through time and experience as the teachers' views move toward those more universally held by practicing scientists.

Introduction

The *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) call for a shift in focus of science education to better prepare students by more accurately modeling science and scientific inquiry. The correlation between innovative teaching methods and higher student achievement has been documented in many countries, but these teaching strategies are sadly lacking in many U.S. science and mathematics classrooms (SWEPT, n.d.). A recent national study of high school chemistry teachers indicated most teachers do not use teaching methods consistent with current national science education goals and still rely primarily on lecture/discussion instruction with occasional verification laboratory activities (Smith, 2002). The most direct mechanism to address this issue and achieve the national science education goals is to improve the quality of practicing high school teachers through high-quality professional development (PD) programs.

The reality is that most PD programs for high school science teachers fall significantly short of national science education goals and fail to impact classroom practices (AASCU, 2001; NRC, 2001). The barriers to reform that may account for the discrepancy between the national goals for science education and classroom practice are well documented and include lack of access to inquiry materials and assessments (Caton, Brewer, & Brown, 2000; Straits & Wilke, 2002), curriculum constraints (Flick, Keys, Westbrook, Crawford, & Carnes, 1997; Keys & Bryan, 2001; Tretter, 2003), inadequate in-service education (Anderson, 1996), teachers tending to teach how they were taught (Borko & Putnam, 1995; Loucks-Horsley & Steigelbauer, 1991), and a lack of scientific training (Loucks-Horsley, & Matsumoto, 1999). Furthermore, underlying many of the teacher-focused barriers are their beliefs and values about the goals of education, teaching, students, and the nature of scientific inquiry (NRC, 1996; NRC, 2000). Therefore, a successful PD program must be structured to overcome these barriers.

Figure 1: Target Inquiry Model

The research described in this paper is part of a larger study of a new model for PD known as Target Inquiry (TI). The TI model (Figure 1) emphasizes the importance of the inquiry process in teaching and learning science by combining a research experience for teachers with curriculum adaptation and action research. TI has been translated into a chemistry emphasis for an existing M.Ed. program and is designed to impact instruction and student outcomes in high school chemistry. TI integrates the key features of effective PD programs (Garet, Porter, DeSimone, Birman, & Yoon, 2001) with experiences individually shown to be helpful to teachers and their students (Berlin, 1996; Keys & Bryan, 2001; SWEPT, n.d.), including curriculum adaptation and action research supported by cohort membership and reflection.

The study of the TI model includes interviewing participating teachers to assess their beliefs about the nature of scientific inquiry before and after key experiences in the TI program to document if and how teachers' beliefs change. However, the variety of models and conceptions of scientific inquiry identified in the baseline interviews prompted the authors to consider how teachers' beliefs may have changed throughout their postsecondary education, and how they might change as they move toward a model of scientific inquiry more universally held by practicing scientists. This required a closer examination of students' and scientists' models and conceptions of inquiry. Acknowledging that the teachers' experiences as science students likely shaped their current views, we attempted to situate them experientially between undergraduate chemistry majors and practicing chemists in academia. The study outlined here describes data collected from undergraduates, high school teachers, and scientists in an effort to better understand how models and conceptions of scientific inquiry might change as the teachers' views move toward those more universally held by scientists. It is our hope that by better characterizing teachers' views relative to students and practicing scientists, we can understand how models of scientific inquiry change through time and experience.

The authors assert that the mechanism by which knowledge of scientific inquiry is formed is embedded in particular experiences in science as students, teachers, and/or practitioners.

Harwood (2004) provided a representation of how practicing scientists view scientific inquiry known as the Activity Model shown in Figure 2. The Activity Model was developed by interviewing 50 scientists from a wide variety of disciplines and asking how they "did" science. As the work presented here aims to better understand teachers' and students' views of scientific inquiry as compared to practicing scientists, the Activity Model was a key component of this study.

The researchers viewed this study through a constructivist lens. Constructivism is a theory of knowledge based on the premise that knowledge only exists in people's minds and that people construct what they know on the basis of their experience (von Glasersfeld, 1995). The authors collected and analyzed data under the presumption that the participants' current views of scientific inquiry are a result of their experiences. More specifically, the authors assert that the mechanism by which knowledge of scientific inquiry is formed is embedded in particular experiences in science as students, teachers, and/or practitioners.

Research Questions

1. How do representations of scientific inquiry of college students and high school teachers compare to those of scientists?
2. How do conceptions of scientific inquiry change over time?

Methods

Participants consisted of 10 high school chemistry teachers (5 males, 5 females) currently participating in the TI program, 8 undergraduate chemistry majors (6 males, 2 females; 2 freshmen and sophomores, 1 junior, and 3 seniors) selected from a group of thirteen volunteers, and 5 chemistry faculty (3 males, 2 females) selected from a group of 8 volunteers. The student participants were selected to maximize diversity based upon gender, year in school, and emphasis within the chemistry major. Four of the 8 participating students had chemistry research experience prior to the interview process. Faculty participants came from a variety of chemistry sub-disciplines including physical, organic, and computational biochemistry.

Data Collection

The TI teachers were asked to respond to journal prompts at the beginning of their summer chemistry research experience. The initial journal prompt asked teachers to discuss their definitions of scientific inquiry. This was followed up in class by having the teachers work in pairs to create models (drawings) to represent scientific inquiry. The teachers were introduced to the Activity Model (Harwood, 2004) and responded to subsequent journal prompts that asked them to compare and contrast their ideas with the Activity Model. The journal responses and artifacts (drawings) were collected.

The chemistry students and faculty were recruited via email and asked to participate in a 20-30 minute interview. Informed consent was obtained from all participants and each person was interviewed by the first author. During the interview, participants were asked about their background in chemistry including any research experience either in chemistry or another discipline. Participants were then asked to define scientific inquiry and describe how scientists do science. During the interview, participants created models (drawings) of scientific inquiry, compared their models with three models that were provided for them, and selected one model as the best representation of scientific inquiry. The provided models were the Activity Model (Harwood, 2004), the Spiral Model (Ludeman & VanZanten, 2006), and the Flowchart Model (Sterner, 1998) as shown in Figures 2-4. The Spiral Model was created by two of the TI teachers and was selected for this study because it elicited the most favorable teacher comments of the five teacher-created models. The Flowchart Model was selected because it resembled the stepwise "scientific method" model described in teacher journals. Interviews were audio taped and participants' models were collected.

Participants created models that varied in structure, organization, activities, and detail. Sample models highlighting the variation between participants are shown in Figures 5-7. Note that these models are not representative of any one group of participants.

Data Analysis

The data collected were systematically analyzed through a step-wise process. Interviews were transcribed and transcripts were read through multiple times in order to

Figure 2: Activity Model

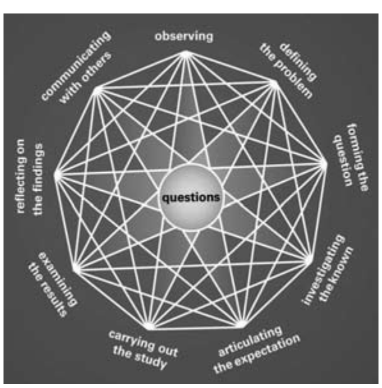


Figure 3: Spiral Model

Figure 4: Flowchart Model

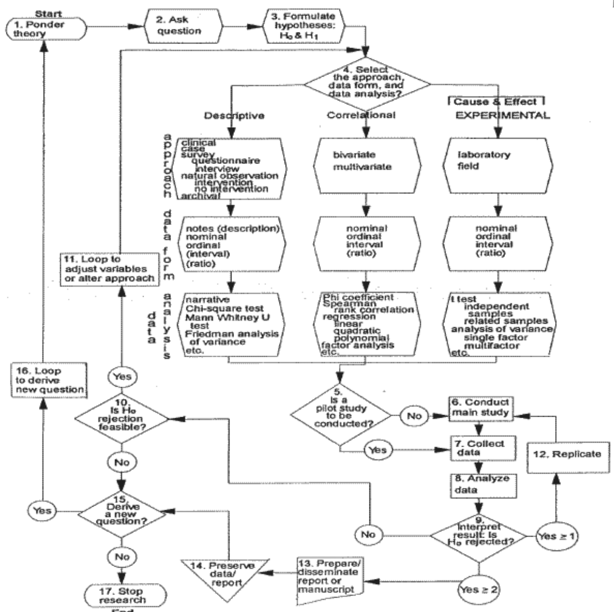


Figure 5: Faculty Model of Scientific Inquiry

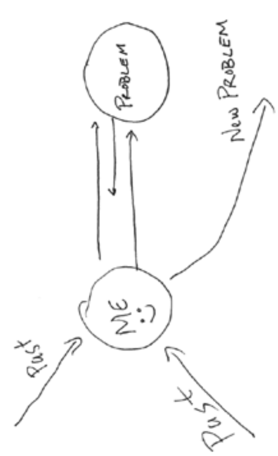


Figure 6: Teacher Model of Scientific Inquiry

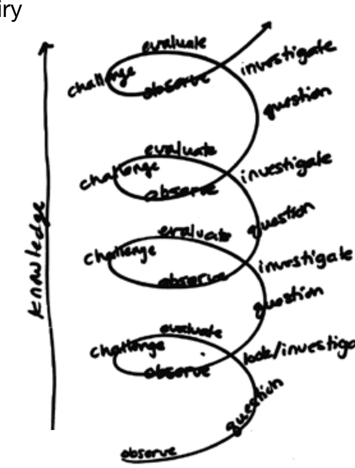
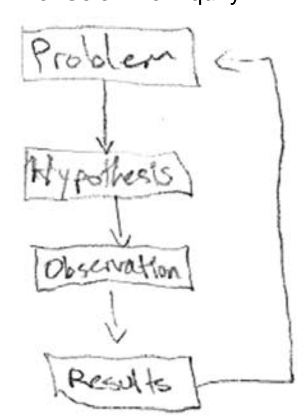


Figure 7: Student Model of Scientific Inquiry



identify common themes. An initial coding scheme was developed based on the activities within the Activity Model. Five interviews were then coded using this coding scheme. Poor inter-rater reliability, with less than sixty percent agreement, warranted a compression of the codes to a final coding scheme of nineteen codes (Table 1). All interviews and journal responses were coded using the final coding scheme in Atlas ti by the first and second authors achieving inter-rater reliability of seventy percent or better for each interview (Miles & Huberman, 1994).

The initial analysis of the teacher data revealed that it was insufficient and incomplete because the teachers did not undergo the same interviewing process as the chemistry faculty and undergraduate students. In order to complete the teacher data, a brief follow-up interview protocol was designed and teachers were interviewed individually by the first author. Teachers were asked in the interview to explain the model they previously drew; compare the Activity, Spiral, and Flowchart Models; and choose which model they felt best represented scientific inquiry and why. The follow-up interviews were audio taped and transcribed. The transcripts were then coded using the final coding scheme in Atlas ti by the first and second authors. Eighty percent or better inter-rater reliability was achieved for each interview.

To examine the data globally and determine which codes occurred more frequently than others, Microsoft Excel was used to create a frequency matrix. To visually display these data, a number line, ranging from no mention of the activity to mention of the activity ten times, was created for each code. Participants were arranged by frequency along the number line categorized as faculty, student, or teacher. The frequency number line for *looping* is provided in Figure 8. Note the increased frequency with the teachers following the research experience as well as the higher frequency of mention among the faculty as compared to most students and teachers. This approach made it easy to compare each participant's result for each code and would prove to be a useful technique later in the analysis.

The teacher data were split into two categories: teachers' ideas expressed through the journal assignments prior to the intensive research experience versus teachers' ideas expressed during the follow-up interviews. These two groups were named "Teacher-Pre" and "Teacher-Post."

Quotations relating to the stepwise nature of the traditional scientific method appeared in all of the participant interviews and were classified as "scientific method." In order to make sense of the remaining themes, the authors further analyzed the faculty interviews. Since the focus of the study was to understand how various groups think of the process of science, it stood to reason that chemistry faculty were authentic practitioners in this area. Using this inductive reasoning, the faculty interviews were examined and the codes were classified as "high," "moderate," or "low," based on the relative emphasis faculty participants put on the themes (Table 1).

In an effort to account for the relative "weights" of the codes (high, medium, and low), codes were then assigned a relative point value based on the ratings from the faculty interviews with high-level codes assigned two points, moderate-level one point, and low-level negative one point. Note that quotations classified as "scientific method" were assigned a relative score of zero. Coded quotations were then evaluated using the relative point values for each code and a total score was obtained (based on frequency) for each participant. This score, known as the Beliefs about Scientific Inquiry (BSI) score, ranged from (-4) to 31 points.

Figure 8: Frequency Number Line for the Code Looping

	No Mention	1-2	3-4	5-6	7-8
Faculty			Faculty 1 Faculty 2 Faculty 3	Faculty 4	Faculty 5
Students	Student 1	Student 2 Student 3 Student 4 Student 5	Student 6 Student 7	Student 8	
Teachers: **Pre-RET**	Teacher 1 Teacher 2 Teacher 3 Teacher 4 Teacher 5 Teacher 6	Teacher 7 Teacher 8 Teacher 9	Teacher 10		
Teachers: **Post-RET**	Teacher 1	Teacher 7 Teacher 9 Teacher 2 Teacher 3 Teacher 4 Teacher 5 Teacher 6	Teacher 10 Teacher 8		

Results And Discussion

To display the BSI scores similarly to how the frequencies of the individual codes were initially analyzed, two master continua were created by

Table 1: Final Coding Scheme with Relative Point Values

Code	Description of Quotation	Rating	Relative Point Value
Direction - anti	No set order, able to go in any order	High	2
Interconnectedness	Connection between lots of activities	High	2
Looping	Continual process with multiple iterations, new questions emerge; refine question	High	2
Reality	Model shows realistic side of research: "how it really happens", "more realistic"	High	2
Communication	Discuss or share ideas with others; publish, present findings	Moderate	1
Investigate Known	Literature search, find out what has been done or what is already known	Moderate	1
Prior Knowledge	Reference to things already learned, background knowledge	Moderate	1
Question as focus	Question is the central focus; Constantly referring to question	Moderate	1
Articulate Expectations	Make a hypothesis or prediction	Scientific Method	0
Carry out Study	Do the experiment, make observations, collect data	Scientific Method	0
Develop Methods	Decide or come up with how to do the experiment	Scientific Method	0
Form Question	Define problem, start with question	Scientific Method	0
Reflect on Findings	Examine results, data analysis, challenging results, drawing conclusions	Scientific Method	0
Direction	Step-by-step process, order is important	Low	- 1
Scientific Method	Any mention of the scientific method.	Low	- 1
Truth	There is a right answer and it can be found.	Low	- 1
Truth Approximation	You can get closer and closer to the "right answer" by repeating the process	Low	- 1
Favorite Model	"I like this one the best."	Unrated	
Interesting	An interesting idea or point.	Unrated	

placing the participants on a number line according to participants' BSI scores: one continuum using teacher-pre scores (Figure 9) and one with teacher-post scores (Figure 10).

To validate these findings, the first and second authors coded each participant's model (drawing) for verbal and/or graphical representations of the activities in the final coding scheme. Using the same relative point system, the participants' models were assigned a numerical score. The following is an example of how the models were coded:

Using the final coding scheme, the faculty model shown in Figure 5 was coded for *Prior Knowledge* (1) and *Direction-anti* (2), earning a score of 3. The teacher model in Figure 6 is the original version of the Spiral Model, which was used in the interview process and was coded for *Direction*

Figure 9: BSI Continuum with Teacher-Pre Scores

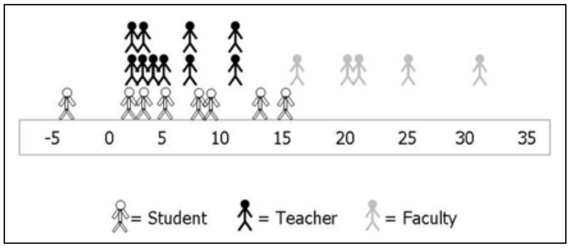
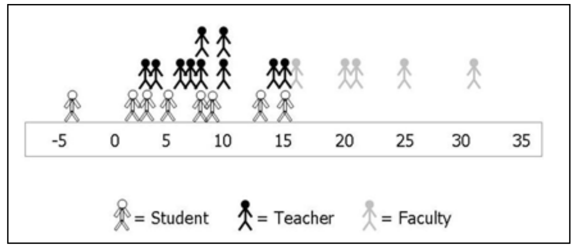


Figure 10: BSI Continuum with Teacher-Post Scores



(-1), *Looping* (2), *Form Question* (0), *Carry out Study* (0) and *Reflect on Findings* (0), yielding a final score of 1. The student model in Figure 7 was coded for *Form Question* (0), *Articulate Expectations* (0), *Carry out Study* (0), *Reflect on Findings* (0), *Direction* (-1), *Scientific Method* (-1), *Looping* (2) giving a final score of 0 points.

Based on scores from all the models, a new continuum was created (scores ranged from -1 to 7). This new continuum was compared to the BSI Continuum and with Teacher-Pre Scores (the teacher models were drawn before their research experience). The relative placement of the participants along the new continuum matched that of the BSI Continuum with Teacher-Pre Scores, with the exception of two models, thus validating the findings from the master continua through triangulation.

The data show that high school chemistry teachers, undergraduate chemistry majors, and chemistry faculty represent scientific inquiry differently. A discussion of findings for each participant group follows.

Undergraduate Chemistry Majors

The results of this study are consistent with prior research indicating that undergraduate chemistry majors hold relatively naïve views of scientific inquiry that focus on the *scientific method* (Bell, Blair, Crawford, & Lederman, 2003). Beyond the steps of the scientific method, every student emphasized *truth*, the idea that a right answer exists or *truth approximation*, the ability of research to approximate the right answer by repeating the procedures, similarly to Bell, et al. (2003). However, seven of the eight

Table 2: Summary of Participants' Favorite Models and BSI Score(s)

Participant	Favorite Model	BSI Score	Participant	Favorite Model	BSI Score Pre	BSI Score Post
Faculty 5	Spiral	31	Teacher 3	Activity	3	15
Faculty 2	Activity	25	Teacher 10	Activity	11	14
Faculty 4	Flowchart	21	Teacher 7	Activity	11	10
Faculty 1	Activity	20	Teacher 8	Flowchart	7	10
Faculty 3	Activity	16	Teacher 9	Activity	5	8
Student 6	Activity	15	Teacher 4	Activity	2	8
Student 2	Activity	13	Teacher 1	Spiral	7	7
Student 3	Activity	9	Teacher 2	Activity	2	6
Student 7	Spiral	8	Teacher 6	Activity	3	4
Student 8	Spiral	5	Teacher 5	Spiral	4	3
Student 5	Own	3				
Student 4	Activity	2				
Student 1	Flowchart	-4				

students also discussed the higher-level idea of *looping*, the emergence of new questions. Also consistent with Bell et al. (2003), student participants rarely mentioned moderate-level activities such as *communication* and *investigating the known*. Moreover, students never discussed *reality*, the idea of illustrating how science is really done.

The four students who chose the Activity Model as the best representation of scientific inquiry made mention of other higher-level activities such as: *interconnectedness,* the connection of various activities and *direction-anti*, the ability to move in any direction throughout the model. According to one of the student participants:

> [The Activity Model] makes the question the central idea, the thing you really want to learn about … and then you just spread out from everything else … and then everything is interconnected. Like you need … you have observing which is also connected to forming a question, investigating, and examining your results. You need it all connected.

Student participants obtained BSI scores that do not correspond with their year in school or whether or not they had any research experience. However, those students with the highest BSI scores chose the Activity Model as the best representation of scientific inquiry, with the exception of one student (Table 2).

Chemistry Faculty

On average, chemistry faculty and undergraduate students discussed lower-level themes equally. However, the difference in their BSI scores can be attributed to the fact that the faculty recognized and discussed higher-level themes such as the ideas of *looping*, *reality*, and *interconnectedness* three times as often as undergraduate student participants.

Faculty participants acknowledged that some processes or activities in science must precede others in their models of scientific inquiry.

Faculty participants acknowledged that some processes or activities in science must precede others in their models of scientific inquiry (*direction* code). As one of the faculty participants stated:

> I agree with them that it can happen in a variety of orders, all of these activities … although certain things can't happen before others. I mean you can't really communicate your results until you've done something.

Faculty participants advocated for a balance between being given no direction and given one, absolute direction. Three of the five participants chose the Activity Model as the better representation of scientific inquiry (Table 2); however, they recommended that the model be modified to highlight activities that typically occur in a particular sequence.

Faculty members also stressed the importance of background knowledge in scientific inquiry, and tended to combine the themes of *investigating the known* and *prior knowledge* into one idea. One theme that faculty participants deemphasized was *articulating expectations*. As one participant stated:

> I think that's dangerous sometimes: to say what you're expecting to get out of a research experience. You can hope, but to actually state it leads you to disregard, in some respect, some observations that don't meet your expectations.

High School Chemistry Teachers

Prior to the summer research experience, the high school chemistry teachers focused primarily on moderate-level activities in their journal responses. However, the teachers' journal entries and models demonstrated a mixture of high and low level ideas as well, including the ideas of *looping* and *direction*. This mixture of ideas is consistent with Windchitl (2004) who found that pre-service teachers' representations of scientific inquiry had facets that were both authentic and limited. The pairing of *looping* and *direction* can be seen in the Spiral Model shown in Figures 3 and 6. As one of the teachers explains:

> When we came up with [the spiral] model, we wanted to show that science doesn't have an end. That you think that you have answer, but really that answer is just a part of another question and it keeps going around and around and around. What you learn in one instance could spark an idea in something else that you hadn't thought of before.

Following the summer research experience, the teachers' ideas of scientific inquiry shifted. A paired samples t test showed that post BSI scores (mean= 8.5, SD= 3.89) were significantly higher than pre BSI scores (mean= 5.5, SD= 3.41) at the p= 0.037 level. Comparing the teacher-pre and teacher-post BSI scores, seven of the ten teachers' scores increased. This increase in score is due to the increased frequency of higher-level activities within the follow-up interviews. The frequency of codes such as *direction-anti* and *looping* doubled following the research experience. Interestingly, six of those seven teachers chose the Activity Model as the best representation of scientific inquiry (Table 2).

While the frequency of high-level activities doubled (on average) after the research experience, the frequency of moderate and low-level activities decreased. The teachers shifted their attention away from the moderate-level ideas of *communication* and *investigating the known*, and chose to focus almost completely on the ideas of *looping*, *interconnectedness*, and *direction-anti*.

It is important to note that the teachers were shown and asked to discuss the Activity Model in a seminar accompanying their summer research experience. This may have predisposed the teachers to select the Activity Model. During the follow-up interview, all of the teachers recalled seeing and discussing the Activity Model; however, not all selected it as the better model.

Conclusions, Implications, and Future Work

In addressing the first research question, it is clear from the analysis that college students and high school teachers represent scientific inquiry differently from practicing scientists. However, the representations within groups are quite varied making it difficult to generate a description that is representative of the views held by all participants in any one particular group. It is noteworthy to mention that the students' and teachers' representations overlapped each other, but were distinct from those of the faculty.

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With respect to the second question, conceptions of scientific inquiry seem to change over experience rather than time for the teachers, but not the students. The teachers' BSI scores significantly increased as a result of the TI research experience. However, with the student participants, the BSI scores did not correspond to their year in school or whether or not they had any research experience. A possible explanation may be apparent when comparing the typical undergraduate research experience with that of TI teachers. The seminar course coupled with the lab research required teachers to reflect on their activities in the lab, and think about how they could model these processes for their students through reforming teaching materials and techniques. As students do not typically have the opportunity to reflect on their lab work, it is possible that deliberate reflection on the research process is necessary to shift views of scientific inquiry to more resemble those of scientists. Schwartz, Lederman, & Crawford found that reflective debriefing sessions and not the research experience improved pre-service teachers' (undergraduates') views of scientific inquiry (as cited in Bell et al., 2003). For teachers, reflection is not only identified as a key activity in the professional development standards (NRC, 1996), but is also a habit of mind central to inquiry, as evidenced by its appearance in the Activity Model.

The coding scheme and rating scale developed here will be used as an additional analysis tool in the larger TI study to determine how teachers' views of scientific inquiry change as they progress through the TI program. In the TI study, teachers are interviewed annually (before, during, and after the program for a total of 5 years). As it is the goal of the program for teachers to more accurately model scientific inquiry, it is critical that they hold views consistent with practicing scientists. The new scheme and scale provide a means to effectively analyze annual teacher interviews to assess if and how their views of scientific inquiry change as a result of participation in the TI program. (More information can be obtained about TI by visiting, www.gvsu.edu/targetinquiry.)

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