Scientific Inquiry with Information Technologies:

High School Students' Experiences*

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Abstract: This initial study focused on high school students' experiences about their understanding of, and abilities necessary to do scientific inquiry, two foci emphasized by the National Science Education Standards in the strand on "science as inquiry". The research method consisted of Likert-scale survey with space provided for students' comments about the two parallel foci of science as inquiry. The data were collected from 45 students (29 females and 16 males) from Grades 9 to 12. The results of this study has indicated that on the average 82.06% and 78.71% of the students developed better understanding of, and abilities necessary to do scientific inquiry, respectively. These increases were further supported by evidence from qualitative data. This study lays the foundation for future studies on mapping learning progressions on scientific inquiry with information technologies. This study reiterates the need to emphasize the importance of "how do we come to know what we know in science".

Introduction

The current standards distinguish between "science as a process" and the "processes of science". The former focuses on the learning of skills, such as observation, inference, and experimentation. The move away from the learning of skills to the latter emphasis requires the combination of processes and scientific knowledge, which calls for the use of scientific reasoning and critical thinking to develop understanding of science. When students engage in

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processes of science, they develop: understanding of scientific concepts; an appreciation of "how we know" what we know in science; understanding of the nature of science; skills necessary to become independent inquirers about the natural worlds; and the dispositions to use the skills, abilities, and attitudes associated with science (NRC, 1996, p. 105).

Within the new frameworks of the processes of science, scientific inquiry involves asking questions that are scientifically oriented; seeking evidence to develop and evaluate explanations that address scientifically oriented questions; formulating explanations from evidence to address scientifically oriented questions; evaluating explanations in light of alternative explanations (particularly those reflecting scientific understanding); and communicating and justifying proposed explanations (NRC, 2000). To enact these principles of scientific inquiry, students need to interpret and respond to criticism from others, formulate appropriate criticisms of others, engage in critical argumentation of their own explanations based on others' feedback, and reflect on alternative explanations (Grandy & Duschl, 2005). Underlying these orientations of science are the radical changes that have occurred in our understanding of multiple aspects of learning: (1) behavioral (change in behavior explained by mental states), (2) cognitive (mental functioning), (3) affective (dispositions including motivation, attitude, interest, and values), (4) social (socially constructed knowledge), and (5) technological (i.e., embedding information technologies based experiences in curriculum that allows for learning flexibility).

Problem Statement

This proposal addresses the "science as inquiry" standards (NRC, 1996) in the context of a three-year NSF project, namely, *Translating Information Technology into Classroom (TITiC)*. In phase 1, teachers are trained in information technology (GIS/GPS, probes and sensors, and communication tools). Phase 1 is preparation for phase 2 where the teachers introduce the technology to their schools and initiate a long-term socio-scientific study with a small group of students. In Phase 3, the IT competent teachers integrate IT into the curriculum because of their experience in Phases 1 and 2. The results that we are reporting in this proposal are gathered from a student survey at the end of the second phase. Based on the standards, which speak to the understanding about inquiry, and abilities necessary to do scientific inquiry, we frame two parallel research questions:

- What are high school students' experiences with respect to understanding of the nature of scientific inquiry after they were engaged in a long-term research project?
- What are high schools students' experiences with respect to developing abilities to do scientific inquiry after they were engaged in a long-term research project?

Design/Procedures

Context of Inquiry

In Phase 1 (specially designed 2-week summer institute), 15 teachers, 5 from three school districts, through a participatory approach, learned the capabilities of the GIS/GPS, Vernier probe wear, the CBL2 interface unit, the TI-84+ calculator, and the LoggerPro software within the authentic context of the watersheds of Lake Erie at Bolles Harbor Center, Monroe, Michigan. At the end of the summer institute, the external evaluators, Mark Jenness and his team, asked teachers to rate their preparation to use specific technologies on a scale of 1(not well prepared) to 4 (well prepared). All technologies received high ratings (SAMPI, 2005): 3.14 for the Logger Pro Software, 3.14 for Vernier probes, 3.43 for the GPS, 3.14 for the Water Test kits, 3.36 for the Spectrophotometer for analyzing water quality, 2.29 for the GIS, and 2.36 for the TITiC Portal. The lessons learned were presented at the AERA Conference (Ebenezer & Hoffman, 2006), and at the 2006 SITE Conference. (Ebenezer, Fader & Speirs, 2006). Positive results and outcomes to date from the TITiC project lend support to the efficacy of the teachers being able to use IT in scientific inquiry. If high quality reform-based professional development of teachers is provided (Supovitz & Turner, 2000), then teaching practices are expected to have a high impact on student learning and education (Borko, 2004, Fullan, 1996). With this leaning, at the end of Phase 2 of the TITiC project, that is, after each teacher had engaged a small group of 3-5 students in a long-term project, we surveyed students' experiences about their understanding of and abilities to do scientific inquiry.

The Nature of Students' Research Projects

At the beginning of the 2005-2006 school year, the TITiC teachers taught their students how to use special technologies to conduct scientific inquiry. Then the teachers engaged these students in a semester-long scientific research projects that were related to their every-day lives. To portray the nature of student research projects, we use students' investigation on the "*Algae in the River Raisin*". Using the Internet, books, and expert knowledge of scientists and teachers, students studied the concepts and theoretical background guiding their research questions. This research group also connected with Mr. Daniel Stenfanski, Monroe County Drain Commissioner, through e-mail and phone interviews and communications, to shape their research direction. Based on their understanding of scientific knowledge and logical reasoning, students set up their hypothesis. After deciding on the tests that need to be conducted, students determined the necessary materials, supplies, and technologies necessary to investigate their research questions. For example, some materials and technologies, which "Algae" students used in water sampling, were: CBL2 interface, TI graphing calculator, Datamate program, Temperature, PH, Salinity and Turbidity, Flow rate sensors, Hach programs, GPS units, Distilled water, Assorted beakers, Graduated cylinder, Chloride 2 indicator powder pillow, potassium per sulfate powder pillow and Turbidity standard 100 NTU. Students analyzed the data and proposed an explanation with strong evidence to make a conclusion. At this phase, they also compared their results with the historical findings. Students in the algae group collaboratively participated throughout the research, and had specific roles and responsibilities in each phase of the project. Together with other TITiC students, algae group presented its research paper to more than 100 participants on May 15, 2006 at Wayne-RESA in the symposium specially organized for this purpose.

Sample

Forty-five students (29 females and 16 males), ages 15 to 17, in Grade 9 (n=8), Grade 10 (n=10), Grade 11 (n=16), and Grade 12 (n=10) from three different public high schools participated in this study. The population of students was from middle socio-economic status homes. 42 students were white Americans, two students were Asians and one was a Native American.

Data Collection

When we developed the items of our Likert surveys, we considered the goals concerning students' understanding of, and abilities to do scientific inquiry emphasized by the National Science Education Standards (NRC, 1996; 2000), and the pertinent literatures (e.g., Grandy & Duschl, 2005). The first part of Likert survey related to students' experiences about their understanding of scientific inquiry consisted of 26 items. The second part of the Likert survey dealing with students' experiences about their abilities necessary to do scientific inquiry consisted of 31 items. For all items on these scales, students were asked to rate "How much did the TITiC program change their understanding of, and abilities necessary to do scientific inquiry?" on a 7-point scale anchored by 1 (not at all) and 7 (a great deal). At the end of each Likert scale, a relevant open-ended question was asked so that students may elaborate their responses to the Likert scale items.

Results and Discussion

Changes in Students' Understanding of Scientific Inquiry

On the average, 82.06% of the students reported that their understanding of scientific inquiry developed in a positive direction after their experience with the TITiC project. It was found that there was no or hardly any change for 4.61% of students in their understanding of scientific inquiry. 6.26% and 5.68% of students reported a little and some changes, respectively, in their understanding of scientific inquiry. All results of the relevant part of the Likert Scale are presented in Table 1. The following excerpts are reflective of students' understanding of scientific inquiry: *"Scientific inquiry involves a lot more than an experiment, you need communication, good data, and a lot of time to think and process ideas." "My understanding of scientific inquiry has changed since the TITiC project because there are many important communication skills needed when conducing certain experiments, etc. in biology. It is very important to gather data, and then get together the next day, review your data, propose your hypothesis, gather evidence that supports your hypothesis, and then come to a conclusion as a team." "My understanding of scientific inquire has changed because I learned about how much background information is need and how important historical facts about the thing being tested. In all, my understanding of the scientific process is greater."*

Table 1. Changes in students' understanding of scientific inquiry after the TITiC project.

After my experience with the TITiC project, I can better understand that…	none at all	hardly any at all	a little	some	a moderate amount	a lot	a great deal
1. Scientific issues must have personal meaning.	1 (2.22%)	2 (4.44%)	3 (6.67%)	1 (2.22%)	6 (13.33%)	1 (2.22%)	21 (46.67%)
2. Scientific questions have personal meaning.	1 (2.22%)	3 (6.67%)	3 (6.67%)	2 (4.44%)	7 (15.56%)	7 (15.56%)	22 (48.89%)
3. Science concepts guide scientific inquiry.	1 (2.22%)	1 (2.22%)	3 (6.67%)	2 (4.44%)	10 (22.22%)	8 (17.78%)	20 (44.44%)
4. Historical and current scientific knowledge influence the design of investigations.	1 (2.22%)	1 (2.22%)	3 (6.67%)	1 (2.22%)	7 (15.56%)	10 (22.22%)	22 (48.89%
5. Scientific inquiry is performed to test ideas.	0	2 (4.44%)	3 (6.67%)	2 (4.44%)	6 (13.33%)	7 (15.56%)	25 (55.56%)
6. Scientific inquiry is performed not to prove or verify scientific theories and laws.	1 (2.22%)	3 (6.67%)	2 (4.44%)	2 (4.44%)	6 (13.33%)	10 (22.22%)	21 (46.67%)
7. Scientific inquiry involves active participation.	0	0	3 (6.67%)	2 (4.44%)	5 (11.11%)	5 (11.11%)	30 (66.67%)
8. Historical and current scientific knowledge influence the interpretation of investigations.	0	0	4 (8.89%)	4 (8.89%)	5 (11.11%)	10 (22.22%)	21 (46.67%)
9. Scientific inquiry involves data gathering.	0	1 (2.22%)	3 (6.67%)	2 (4.44%)	4 (8.89%)	8 (17.78%)	27 (60.00%)
10. Scientific inquiry involves data analysis.	0	1 (2.22%)	3 (6.67%)	2 (4.44%)	4 (8.89%)	7 (15.56%)	28 (62.22%)
11. Scientists depend on technology to enhance the gathering of data.	0	2 (4.44%)	4 (8.89%)	2 (4.44%)	6 (13.33%)	5 (11.11%)	26 (57.78%)
12. Scientists depend on technology to enhance the manipulation of data.	0	2 (4.44%)	2 (4.44%)	5 (11.11%)	5 (11.11%)	7 (15.56%)	24 (53.33%)
13. Mathematical tools and models guide and improve posing of scientific questions.	0	2 (4.44%)	4 (8.89%)	4 (8.89%)	6 (13.33%)	10 (22.22%)	19 (42.22%)
14. Mathematical tools and models guide and improve gathering scientific data.	0	2 (4.44%)	3 (6.67%)	4 (8.89%)	6 (13.33%)	10 (22.22%)	20 (44.44%)
15. Mathematical tools and models guide and improve constructing scientific explanations.	0	3 (6.67%)	3 (6.67%)	2 (4.44%)	6 (13.33%)	9 (20.00%)	22 (48.89%
16. Mathematical tools and models guide and improve communicating scientific results.	0	3 (6.67%)	3 (6.67%)	2 (4.44%)	6 (13.33%)	10 (22.22%)	21 (46.67%)
17. Historical and current scientific knowledge influence the evaluation of explanations.	0	2 (4.44%)	3 (6.67%)	4 (8.89%)	8 (17.78%)	7 (15.56%)	21 (46.67%)
18. Explanations are proposed based on evidence and logic.	0	3 (6.67%)	2 (4.44%)	3 (6.67%)	5 (11.11%)	9 (20.00%)	23 (51.11%)
19. Evidence and logic are used to support or reject ideas.	0	3 (6.67%)	2 (4.44%)	2 (4.44%)	5 (11.11%)	11 (24.44%)	22 (48.89%
20. Not all data are valid.	0	1 (2.22%)	3 (6.67%)	3 (6.67%)	4 (8.89%)	10 (22.22%)	24 (53.33%)
21. There is distinction between	1	2	3	3	8 (17.78%)	8 (17.78%)	20

	evidence and data.	(2.22%)	(4.44%)	(6.67%)	(6.67%)			(44.44%)
22.	Evidence should be selected from data.	0	2 (4.44%)	2 (4.44%)	5 (11.11%)	7 (15.56%)	7 (15.56%)	22 (48.89%
23.	Communication is a part of scientific inquiry.	0	1 (2.22%)	4 (8.89%)	0	6 (13.33%)	10 (22.22%)	24 (53.33%)
24.	Criticism is a part of scientific inquiry.	0	2 (4.44%)	3 (6.67%)	3 (6.67%)	7 (15.56%)	10 (22.22%)	20 (44.44%)
25.	Scientific inquiry involves review process.	0	2 (4.44%)	3 (6.67%)	1 (2.22%)	6 (13.33%)	9 (20.00%)	24 (53.33%)
26.	Scientific inquiry involves reflection.	0	2 (4.44%)	2 (4.44%)	1 (2.22%)	3 (6.67%)	10 (22.22%)	27 (60.00%)

Students have indeed focused on the importance of communication, good data collection, much time to think and process ideas, gathering evidence to support hypothesis, coming to collective conclusions, the need for background information for the study of the problem. All of these elements are important aspects of the nature of scientific inquiry supported by current literature in science education (NRC, 2000; Grandy & Duschl, 2005).

<u>Changes in Students' Abilities Necessary to Do Scientific Inquiry</u>

On the average, 78.71% of the students reported that their abilities necessary to do scientific inquiry developed in a positive direction after their experience with the TITiC project. It was found that there was no or hardly any change for 4.52% of students in their abilities necessary to do scientific inquiry. 6.67% and 10.11% of students reported a little and some changes, respectively, in their abilities necessary to do scientific inquiry. All results of the relevant part of the Likert Scale are presented in Table 2. The following excerpts are reflective of students' abilities necessary to do scientific inquiry**:** *"My ability to do scientific inquiry has changed because of this project because creating a webpage gave me the opportunity to post my ideas, and then give other people to formulate their own personal hypotheses. My ability to form theories and opinions based off of other peoples research has also improved." "I have become more confident with scientific inquiry and feel more confident sharing my opinions and presenting research. I have learned how to accept criticism and how to give constructive criticism to my peers." "I feel that I am much better at forming researchable questions that can potentially answer a question. I feel much more confident in my ability to formulate experiments and conduct them. I also feel much more confident about being able to understand the data I collect and using it to reach valid conclusions." "I've learned how to research primary sources. With these primary sources I can conduct my own researchable question and theories. The* *sources back up my theories. I learned how to tie in primary sources with an actual experiment and come up with a conclusion."* Based on the above quotes, students have developed their abilities to post ideas, form theories, give and accept criticism, frame researchable questions, design and conduct experiments, understand the data collected and reach valid conclusions, and link primary sources to actual experiment. All of these elements are important aspects of the nature of scientific inquiry supported by current literature in science education (NRC, 2000; Grandy & Duschl, 2005).

Table 2. Changes in students' abilities necessary to do scientific inquiry after their experience with the TITiC project.

After my experience with the TITiC Project, I am more able to…	none at all	hardly any at all	a little	some	a moderate amount	a lot	a great deal
1. Identify scientific issues..	0	3 (6.67%)	1 (2.22%)	3 (6.67%)	7 (15.56%)	11 (24.44%)	20 (44.44%)
2. Pose scientific research questions.	0	2 (4.44%)	2 (4.44%)	5 (11.11%)	4 (8.89%)	11 (24.44%)	21 (46.67%)
3. Refine scientific research questions.	0	3 (6.67%)	2 (4.44%)	5 (11.11%)	5 (11.11%)	10 (22.22%)	20 (44.44%)
4. Identify concepts that guide scientific investigations.	0	3 (6.67%)	2 (4.44%)	4 (8.89%)	9 (20.00%)	9 (20.00%)	18 (40.00%)
5. Formulate hypothesis to test ideas.	0	2 (4.44%)	3 (6.67%)	2 (4.44%)	9 (20.00%)	7 (15.56%)	22 (48.89%)
6. Design experiments.	0	1 (2.22%)	4 (8.89%)	6 (13.33%)	7 (15.56%)	7 (15.56%)	20 (44.44%)
7. Conduct scientific investigations.	0	1 (2.22%)	4 (8.89%)	3 (6.67%)	10 (22.22%)	8 (17.78%)	19 (42.22%)
8. Seek evidence to develop explanations.	0	1 (2.22%)	3 (6.67%)	3 (6.67%)	10 (22.22%)	9 (20.00%)	19 (42.22%)
9. Seek evidence to evaluate explanations.	0	1 (2.22%)	3 (6.67%)	3 (6.67%)	10 (22.22%)	9 (20.00%)	19 (42.22%)
10. Use mathematics to support scientific investigations.	1 (2.22%)	3 (6.67%)	5 (11.11%)	3 (6.67%)	9 (20.00%)	6 (13.33%)	18 (40.00%)
11. Use technology to support scientific investigations.	0	3 (6.67%)	3 (6.67%)	4 (8.89%)	8 (17.78%)	9 (20.00%)	18 (40.00%)
12. Collect data.	0	1 (2.22%)	4 (8.89%)	2 (4.44%)	5 (11.11%)	13 (28.89%)	20 (44.44%)
13. Record data.	0	1 (2.22%)	5 (11.11%)	5 (11.11%)	3 (6.67%)	11 (24.44%)	20 (44.44%)
14. Analyze data.	0	1 (2.22%)	4 (8.89%)	2 (4.44%)	5 (11.11%)	12 (26.67%)	21 (46.67%)
15. Discuss data.	0	1 (2.22%)	4 (8.89%)	2 (4.44%)	6 (13.33%)	11 (24.44%)	21 (46.67%)
16. Select appropriate data.	0	2 (4.44%)	2 (4.44%)	4 (8.89%)	6 (13.33%)	11 (24.44%)	20 (44.44%)

17. Deal with data that do not match.	0	2 (4.44%)	2 (4.44%)	7 (15.56%)	6 (13.33%)	8 (17.78%)	20 (44.44%)
18. Distinguish between evidence and data.	1 (2.22%)	3 (6.67%)	1 (2.22%)	5 (11.11%)	9 (20.00%)	7 (15.56%)	19 (42.22%)
19. Select evidence from data.	0	3 (6.67%)	3 (6.67%)	5 (11.11%)	6 (13.33%)	8 (17.78%)	20 (44.44%)
20. Formulate explanations and models using evidence and reason.	0	2 (4.44%)	2 (4.44%)	5 (11.11%)	11 (24.44%)	6 (13.33%)	19 (42.22%)
21. Formulate explanations and models using current scientific understanding.	0	2 (4.44%)	2 (4.44%)	4 (8.89%)	12 (26.67%)	8 (17.78%)	17 (37.78%)
22. Recognize and analyze alternative explanations and models.	0	2 (4.44%)	4 (8.89%)	6 (13.33%)	7 (15.56%)	7 (15.56%)	19 (42.22%)
23. Evaluate explanations and models using evidence and reason.	0	2 (4.44%)	4 (8.89%)	5 (11.11%)	9 (20.00%)	7 (15.56%)	18 (40.00%)
24. Evaluate explanations and models using current scientific understanding.	0	3 (6.67%)	3 (6.67%)	4 (8.89%)	9 (20.00%)	10 (22.22%)	16 (35.56%)
25. Revise explanations and models using evidence and reason.	0	2 (4.44%)	4 (8.89%)	5 (11.11%)	12 (26.67%)	4 (8.89%)	18 (40.00%)
26. Revise explanations and models using current scientific understanding.	0	2 (4.44%)	3 (6.67%)	7 (15.56%)	8 (17.78%)	8 (17.78%)	17 (37.78%)
27. Make conclusions.	0	2 (4.44%)	3 (6.67%)	4 (8.89%)	7 (15.56%)	9 (20.00%)	20 (44.44%)
28. Communicate research methods and findings.	0	1 (2.22%)	4 (8.89%)	5 (11.11%)	8 (17.78%)	7 (15.56%)	20 (44.44%)
29. Defend scientific argument.	0	2 (4.44%)	4 (8.89%)	8 (17.78%)	7 (15.56%)	9 (20.00%)	15 (33.33%)
30. Criticize peers' research.	1 (2.22%)	2 (4.44%)	2 (4.44%)	8 (17.78%)	6 (13.33%)	12 (26.67%)	14 (31.11%)
31. Criticize my own explanations.	1 (2.22%)	1 (2.22%)	2 (4.44%)	7 (15.56%)	7 (15.56%)	11 (24.44%)	1616 (35.56%)

Implications

This study indicates students' experiences in building capacity and competency in scientific inquiry. This study lays the foundation for future studies on mapping learning progressions on scientific inquiry with information technologies. We now have a better idea of how high school students respond to their experiences in long-term research projects. This study reiterates the need for transformative curriculum models to re-think school science—not only to stress science concepts in science learning and education but also to emphasize the importance of "how do we come to know what we know and why we know it" via social (dialogical) processes. This study is a step forward to help scholars and practitioners transform thinking about the nature of scientific inquiry and its role in science education. This paper contributes to the interests of science educators because very few empirical studies are based on the standards of "science as inquiry"—the understanding of and abilities to do scientific inquiry. This study has much relevance because students conducted the scientific inquiry on authentic socio-scientific issues in- and out-of-school time.

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