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Successful Use of Science Process Skills by Middle School Students

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Abstract

Two Iowa Chautauqua sites were selected for evaluating student use and understanding of six complex science process skills designed for 5th and 6th graders. Control teachers were selected from nearby schools that had no knowledge of Chautauqua Programs. Iowa Chautauquas are unique with respect to their being full year long efforts. A Research Panel, consisting of at least four members, was asked to evaluate students during personal interviews involving their use and understanding of the six skills. There was also interest in describing behaviors of students in the two types of classrooms (Chautauqua vs Control). In addition to the Research Panel, other visitors often included pre-service teachers. A third effort was asking students to offer their own meaning and use of each of the six science process skills. The responses to these uses were also evaluated by members of the Research Panel. Chautauqua teachers were found to be significantly better than Control teachers in all three instances, namely use and understanding of process skills, observable student classroom behaviors, and the questions and examples offered by students concerning the six process skills.

Keywords: formulating hypotheses, making operational definitions, controlling and manipulating variables, experimenting, interpreting data, formulating models

A recent publication focused on the use and understanding of six science process skills involving 3rd and 4th grade level students at two separate Iowa Chautauqua sites (Faheem, Al-Alsheikh, Yager, S., Hacieminoglu, & Yager, R., 2015). Since that publication focused only on

3rd and 4th grade students, this study focuses on 5th and 6th grade level students at two different Iowa Chautauqua sites involving Chautauqua teachers and Control teachers having no previous Chautauqua experiences. The two teacher groups were designed to illustrate the successes involving the more complex science process skills that were identified as appropriate for use with middle grade level students (Livermore, 1964).

The Iowa Chautauqua program is unique in that it aims to improve K-12 science learning by broadening teacher views concerning the nature of science and technology. It is a program aimed to improve student learning and their actual "doing" of science instead of students merely remembering information from textbooks, laboratory manuals, and teacher lectures. Such "doing" of science involves the Exploration of the natural world, seeking Explanations of objects and events encountered, and including Evidence for the explanations proposed.

Another major uniqueness of the Chautauqua programs is that they consist of year-long efforts. Most professional development programs consist only of two or three weeks with no follow-up actions to indicate successes and/or failures. A year-long Chautauqua sequence includes the following three features: 1) Two or Three Week Summer Workshops, 2) Three Day Fall Short Courses; and 3) Three Day Spring Short Courses. All three meetings also provided personal communications among participating teachers. The continuance of communication among teachers was encouraged throughout the whole calendar year.

The Iowa Chautauqua Programs were successful because of major National Science Foundation (NSF) funding over a period of more than thirty years. Just as the Iowa Chautauqua programs were funded by NSF, another program called Science: A Process Approach (SAPA) was also funded by NSF. SAPA provided a way of defining successes (as well as failures) with evidence for improving student learning. The science process skills identified by SAPA for middle schools were the tools that both scientists and students use to investigate the world around them and to evaluate the actual personal "doing" of science.

Livermore's (1964, p. 273) definitions of the six science process skills for use with middle school students are central to this research effort. They are:

- **Formulating Hypotheses --** stating the expected outcome of an experiment.

- **Making Operational Definition** -- stating how to measure a variable in an experiment.

- **Controlling and Manipulating Variables --** being able to identify variables that can affect an experimental outcome, keeping most constant while manipulating only the independent variable.

- **Experimenting** -- being able to conduct an experiment, including asking an appropriate question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment, and interpreting the results of the experiment.

- **Interpreting Data --** organizing data and drawing conclusions from them.

- **Formulating Models --** creating a mental or physical model of a process or event.

Reform Teaching vs Control Teaching

The following nine reforms for science teaching can characterize science teaching in K-16 grades. There are major contrasts between teachers having Chautauqua teaching experiences (Reform Effort Teaching) and Control teaching (Typical Classroom Teaching by teachers without Chautauqua experiences). Chautauqua teaching changes the typical classroom focus of teaching by involving students in all aspects. Chautauqua teaching features are the actual "doing" of science which involves the Exploration of the natural world seeking Explanations of objects and events encountered while also including Evidence to support the results. Nine reform efforts were central to the "old" National Science Education Standards (NSES, 1996) and continue to be used today to promote new Standards and future reform efforts. These differences are offered to illustrate *typical teaching* by "conscientious" teachers who typically use textbooks, laboratory manuals, and lectures.

The research efforts for this study provide comparisons of Chautauqua and Control teaching and their impacts on student learning. This research involves the same teachers and students over the same academic year at two Chautauqua Sites. The Control teachers were typical teachers who use textbooks, laboratory manuals, and lectures for teaching. They were selected by local Area Education Agency (AEA) staff in Iowa and were from nearby schools. The Chautauqua and Control teachers were the same with regard to age, gender, and having at least four years of teaching experience (but no more than ten years). The following teaching contrasts illustrate the differences between Chautauqua and Control teaching which are central to this research effort. Nine features were used to describe the reforms desired. A and B illustrate the differences for the nine features used for this research report. These are:

A. Reform Teaching (Chautauqua)	B. Typical Teaching (Control)
Responding to interests, strengths, experiences, and ideas of students	Treating all students alike and not as individuals
Encouraging new curriculum structures using suggestions from students	Following only what is in textbooks, laboratory manuals, or teacher lectures
Focusing on the use and understanding of information, ideas, and inquiry processes suggested by students	Focusing only on student acquisition of information occurring in classrooms
Guiding and helping students to be active in exploring their individual inquiries	Information provided by lectures, textbooks, and teacher demonstrations to be remembered for tests
Offering opportunities for discussion and debate among students	Students asked to recite what they are assigned to do
Assessing student understanding as a continuing effort which involves students in the process	Students tested on factual information from textbooks at the end of units and/or chapters

Sharing responsibilities for learning with students	Teachers maintain authority in classroom
Perceiving classrooms as communities with cooperation and respect for everyone	Expecting competition for learning among students
Enhancing teaching and learning by other teachers in the school	Teachers make their own individual lesson plans with little or no student input

A Research Panel was formed to collect and evaluate information involving student use and understanding of the six science process skills, observations of student behaviors in classrooms, and interpretations of students concerning their explanations and specific use of all six process skills. The Research Panel was co-chaired by local regional education employees. The panel always included at least four members, but sometimes up to ten or twelve. This panel included the primary university researcher, a PhD student with research expertise who assisted with all MS students (for their MS Theses), successful past Teacher Leaders, new Teacher Leaders, and school administrators.

Research Results

The three major research foci for this report involve the use and understanding of six science process skills, observable student classroom behaviors, and the actual student use of the six science process skills. All three kinds of information were collected and evaluated by members of the Research Panel for teachers at both sites.

For the first effort all students were interviewed by members of the Research Panel regarding their use and understanding of the six skills. The interview results were collected and evaluated by the Research Panel to indicate the percentage of students who understood the different skills and to what degree the students could use the skills. A scale of 1 to 4 was used with 1 being excellent and 4 indicating the student did not understand the skill. These data were collected and evaluated at the Spring Short Course (April) after a full academic year.

Table 1 indicates that out of 128 students enrolled in Chautauqua classrooms at Site One indicate that 82% of them reported their use and understanding of the *Formulating Hypotheses* skill. However, only 18% of the 85 students in the Control classrooms indicated the use and understanding of the same skill. Table 1 indicates that out of 144 students enrolled in Chautauqua classrooms at Site Two 92% of the students indicated their use and understanding of the *Formulating Hypotheses* skill. Again, only 18% of 126 students in the Control classrooms indicated their use and understanding of the same skill. The science process skill noted to be the most successful at both Chautauqua Sites was *Interpreting Data*. Out of 128 students taught by Chautauqua teachers, 90% of the students indicated their use and understanding of this skill. However, only 29% of the 85 students in the Control taught classroom indicated their use and understanding of the same skill. Similar differences in percentage were noted at Chautauqua Site Two.

Formulating Models were identified at both Chautauqua Sites as being the most difficult process skill for students to use and understand. Out of 128 Chautauqua taught students at Site One 60% indicated their use and understanding of this skill; but only 8% of the 85 Control taught

students indicated their use and understanding of the same skill. Similar differences in difficulty of this science process skill were noted at Chautauqua Site Two. Chautauqua and Control taught students involving their use and understanding of the other three science process skills indicated similar differences in percentages of student use and understanding at both Chautauqua Sites (See Table 1).

Table 1
Percentages of Fifth and Sixth Grade Students Using and Understanding Six Science Process Skills When Taught by Chautauqua Teachers and Those Taught by Control Teachers from Two Chautauqua Sites

	Chautauqua Teachers	Control Teachers	z	p
Site 1				
Formulating Hypotheses	82	18	9.226	0.0001
Making Operational Definitions	81	19	8.932	0.0001
Controlling and Manipulating Variables	78	9	9.864	0.0001
Experimenting	84	13	10.214	0.0001
Interpreting Data	90	29	9.181	0.0001
Formulating Models	60	8	7.611	0.0001
Chautauqua Teachers: 8 Students: 128 Control Teachers: 5 Students: 85				
Site 2				
Formulating Hypotheses	92	18	12.269	0.0001
Making Operational Definitions	66	9	9.562	0.0001
Controlling and Manipulating Variables	84	24	9.909	0.0001
Experimenting	93	19	12.311	0.0001
Interpreting Data	94	23	11.927	0.0001
Formulating Models	53	8	.909	0.0001
Chautauqua Teachers: 9 Students: 144 Control Teachers: 7 Students: 126				

A second focus was the observations of student behaviors by the Research Panel and how they differed between Chautauqua and Control classrooms. The observable classroom behaviors of both teachers and students were described by the Research Panel and numerous other observers. Other observers frequently included pre-service teachers, other teachers in the school, parents, school board members, school administrators, and even community leaders.

Table 2 indicates the behaviors and actions observed in both 5th and 6th grade level classrooms. The observations were collected and reported at the Spring Short Course (April) after a full academic year. Some of the most frequently observed behaviors of teachers and students are included as Table 2.

Table 2
How Behaviors of Fifth and Sixth Grade Level Students Differ in Chautauqua and Control Classrooms

Classroom Behaviors (Chautauqua)	Classroom Behaviors (Control)
Students are allowed class time to explore	Students mostly use textbooks
Students are provided feedback from their teachers and other students	Students are asked to remember textbook materials for testing
Students work in small groups	Students work individually
Students write in journals of their findings	Students have no input into daily lesson plans
Students ask other students for help and advice	Students do not select their own projects
Students use questions from other students	Students do not seek outside information from others
Students do investigations with other students	Students are encouraged to take notes from the teacher and chalkboard
Students learn how to solve their own problems	Students are all treated alike
Students seek outside help and other resources not in textbooks	Students are tested at the end of units and chapters in textbooks

The third focus was asking students about their own understanding and actual use of the six science process skills. One major issue indicated by students was the use of the sixth science process skill, namely "Formulating Models." Students found this process skill to be the most difficult skill to use and understand.

Members of the Research Panel were also involved with observing students in their actual "doing" (use) of the science process skills in science classrooms. Students were asked to describe their understanding of each of the six science process skills. Table 3 is an illustration of

students using and understanding the different skills at both Chautauqua sites. While only two examples are included, many other demonstrations were observed by the Panel indicating student use and their level of understanding involving all six science process skills in Chautauqua taught classrooms. No similar results were collected and/or observed in Control classrooms. Table 3 illustrates a group of students in their own setting indicating their own use and understanding of the six science process skills at the two Chautauqua sites.

Table 3
Illustrations of Student Use of All Six Science Process Skills in Chautauqua Taught Classrooms

Site 1:

Science Process Skills	Student Use
Formulating Hypotheses	It was thought that Maracondo Fever spreads by mosquitoes because it was in the blood
Making Operational Definitions	Data collected from infected and healthy people
Controlling and Manipulating Variables	Testing factors: people who slept on mats, had/have cats, attended fiesta, lived in houses, used insect netting, ate local foods
Experimenting	Compare infected people with healthy people
Interpreting Data	Data indicated most people were infected who slept on mats and attended fiesta. People least infected had/have cats, lived in houses, had insect netting, ate local foods. Evidence indicated that mice were the cause of Maracondo Fever and not mosquitoes
Formulating Models	A flow chart was the only model used

Site 2:

Science Process Skills	Student Use
Formulating Hypotheses	Is snow collected from around the Red Monkey Bars safe to drink
Making Operational Definitions	Levels of snow were tested for pH and nitrate levels
Controlling and Manipulating Variables	Levels of pH needed to be between 6.5 and 9.0 and nitrate needed to be less than 10 parts per million to be safe for drinking
Experimenting	The pH was tested three times and had an average of 7.0. Nitrates had an average of 0 ppm after testing three samples
Interpreting Data	The pH and nitrates were within the safe ranges making the water was safe to drink
Formulating Models	The Red Monkey Bars were replicated and red stickers were used to indicate areas where samples were collected

Implications

Chautauqua programs are successful because they are more student-centered and involve observations for a full academic year. Chautauqua teachers encourage students to initiate something personal to study and investigate. When students use something personal to study, they become more involved in the "actual doing" of science by Exploring the natural world and seeking Explanations of objects and events encountered. They also offer evidence of their explanations. Students in Chautauqua classrooms challenge each other, as well as themselves, to answer their own questions through their own "exploring." Students learn to work together. They ask more questions, express personal ideas, and respect ideas of other students. Students became more involved in science and indicate their liking science more if they focus with "minds-on."

A Saturday afternoon session was often hosted for students to demonstrate and showcase their use and understanding of the science process skills which had been investigated throughout the academic year. The student demonstrations indicate how science teaching in Chautauqua classrooms was conducted and how such meaning of science could make a difference in student learning. The students were excited to show what they had done in their science classes throughout the academic year. Parents, teachers, school administrators, school board members, community leaders, as well as local media were all invited to attend the sessions and to see first-hand what the students had achieved. The local media representatives were invited to publicize the accomplishments and learning experiences indicated by students including photos and student stories.

A more positive attitude was expressed by students concerning science and their interest in exploring other features of the other science domains. All six "domains" of science represent facets which can also be used to reform science teaching, student assessment, and science content. The six science "domains" were first proposed by McCormack and Yager in 1989. They are namely Concepts, Processes, Creativity, Attitude, Applications, and Worldview. Concepts and Process Skills are what most scientists know and do. They represent a very small fraction of the human population (0.000059%) of the whole world (Hurd, 1991). Very few teachers have ever experienced real "doing" of science themselves. If we are to achieve real student learning, we need to consider all six science domains. It is obvious when the science process skills indicate student successes; the other science domains are also successful. The concept and process domains are seen as traditional teaching while creativity and attitude domains are the two enabling domains. The application domain allows using concepts and processes in new contexts and the worldview domain involves the examining of philosophy, history, and sociology of the whole science enterprise. All six science domains support successful student learning. We need science teaching to focus on all six science domains not just process skills. Other strategies that engage students, promote active learning, and boost achievement were reported in a recent publication by Antonetti and Graver (2015).

Conclusions

This research effort indicates that Chautauqua taught students have a *significantly higher percentage* of use and understanding of the science process skills identified for 5th and 6th grade level students. The observable behaviors of students in Chautauqua classrooms indicate more

student involvement and participation when compared to Control classrooms. Chautauqua teaching is significantly different from Control teaching in that it is more student-centered and less teacher-centered. Students in Chautauqua taught classrooms indicated their understanding of the six science process skills by questions they asked and situations offered for each of the six skills. The students found some of the process skills to be harder to use and understand then others as they worked through their personal science experiments. Chautauqua teaching was found to not only change the way teachers teach, but even more importantly, the way students learn. Chautauqua teaching results in the real "doing" of science and changes the science classroom focus from a teaching focus to a student learning focus. As teachers in schools in surrounding areas observed Chautauqua teaching, they expressed interest and often requested to be included in future programs.

The actions of Chautauqua teaching include ways to encourage real student learning and the actual "doing" of science. We need to shift the major education focus to be more student-centered. Classrooms need to be more focused on "Reform Teaching" and less on "Typical Classroom Teaching." Chautauqua teaching continues to change the way teaching should be if students are to really learn and experience the "doing" science. Chautauqua teaching also promotes creativity and attitudes of students in science classrooms as well as the other science domains!

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