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Impact of a Scientist–Teacher Collaborative Model on Students, Teachers, and Scientists

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Collaborations between the K-12 teachers and higher education or professional scientists have become a widespread approach to science education reform. Educational funding and efforts have been invested to establish these cross-institutional collaborations in many countries. Since 2006, Taiwan initiated the High Scope Program, a high school science curriculum reform to promote scientific innovation and inquiry through an integration of advanced science and technology in high school science curricula through partnership between high school teachers and higher education scientists and science educators. This study, as part of this governmental effort, a scientist–teacher collaborative model (STCM) was constructed by 8 scientists and 4 teachers to drive an 18-week high school science curriculum reform on environmental education in a public high school. Partnerships between scientists and teachers offer opportunities to strengthen the elements of effective science teaching identified by Shulman and ultimately affect students' learning. Mixed methods research was used for this study. Qualitative methods of interviews were used to understand the impact on the teachers' and scientists' science teaching. A quasi-experimental design was used to understand the impact on students' scientific competency and scientific interest. The findings in this study suggest that the use of the STCM had a medium effect on students' scientific competency and a large effect on students' scientific individual and situational interests. In the interviews, the teachers indicated how the STCM allowed them to improve their content knowledge and pedagogical content knowledge (PCK), and the scientists indicated an increased knowledge of learners, knowledge of curriculum, and PCK.

Keywords: *Science teaching; Teacher–scientist collaboration or partnership; Scientific competency*

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Collaborations between the K-12 teachers and higher education or professional scientists have become a widespread approach to science education reform (Houseal, Abd-El-Khalick, & Destefano, 2014; Wormstead, Becker, & Congalton, 2002). UNESCO's (2010) *Current Challenges in Basic Science Education* reported cases of collaboration between scientists, science educators, teacher educators and schools, and highlighted their 'powerful deep changes in students' science learning' (p. 41). Educational funding and efforts have been invested to establish these cross-institutional collaborations in many countries. In 1999, the National Science Foundation (NSF) in the USA provided generous stipends for graduate students in science, technology, engineering, and mathematics (STEM) disciplines to work with teachers and students in K-12 schools through the Graduate Teaching STEM Fellows in K-12 Education (GK-12) Program. The GK-12 Program was designed to help prepare STEM graduate students by imparting to them the skills to communicate science concepts and research to a variety of audiences (NSF, 1999). In 2001, the US Department of Education initiated the Mathematics and Science Partnerships Program to establish partnerships between K-12 schools and the STEM faculty in institutions of higher education with the goal of increasing student performance in mathematics and science by enhancing the content knowledge (CoK) and pedagogical skills of classroom teachers (U.S. Department of Education, 2001). In 2002, the Japanese Ministry of Education, Culture, Sports, Science and Technology's (MEXT) launched a three-year Super Science High School program (Japanese Ministry of Education, 2002) as part of its 'Science Literacy Enhancement Initiatives' to develop a curriculum in mathematics, physics, biology, chemistry, and earth science for gifted students. MEXT selects 26 high schools for participation every year, and 77 schools applied for the project in the first year. Selected high schools are expected to develop curricula based on science and mathematics in cooperation with universities or research institutes. Specialists in each field and researchers in education for each subject make up the research group that will examine and analyze their activities and curricula.

In 2006, Taiwan's National Science Council (NSC) initiated the High Scope Program, a high school science curriculum reform to promote scientific innovation and inquiry through an integration of advanced science and technology in high school science curricula (NSC, 2006). The core of the initiative was the synergic partnership between high school principals and teachers and higher education scientists and science educators. Throughout Taiwan, 28 high schools joined the program, and the current study reports the curriculum reform that took place at one of the participating high schools, in which the field of environmental education was chosen as the theme for the science curriculum. Environmental education provides knowledge regarding the biological, ecological, and physical nature of the environment, promotes awareness of related problems and issues, and provokes responsible environmentally sound behaviors (UNESCO, 1987). The United Nations Decade of Education for Sustainable Development has identified important issues related to environmental education, such as natural resources, climate change, rural transformation, sustainable urbanization, and disaster prevention and mitigation, and such initiatives have taken place over the past few years in the Asia-Pacific region (Ryan, Tilbury, Corcoran, Abe, & Nomura, 2010; UNESCO, 2005). The cross-disciplinary nature of environmental education calls for a collaborative and integrative teaching model that congregates teachers, scientists, and professionals with diverse expertise and experience.

Scientist–Teacher Collaborative Model

A scientist–teacher collaborative model (STCM) was constructed to drive the high school science curriculum reform in our study (Figure 1). The aim was to optimize and synthesize forms of knowledge related to science teaching through partnerships between scientists and teachers, such scientist–teacher collaboration extends from a long-standing practice of team teaching by a group of teachers within the same school. Team teaching is built upon collegiality and marked by professional dialogue, flexible teaching modes, and sharing of teaching media (Davis, 1995; Hargreaves, 1994). Studies have shown that team teaching enriches courses with integrated, diversified, and innovative activities and encourages a positive attitude, higher self-esteem, and enhanced interest in learning (Tobin, Zurbano, Ford, & Carambo, 2003), and also offers diverse expertise, perspectives, and teaching styles from different teachers (Buckley, 2000). Our study's STCM followed the same three implementation stages that Buckley (2000) identified for team teaching: (1) planning: co-create a teaching

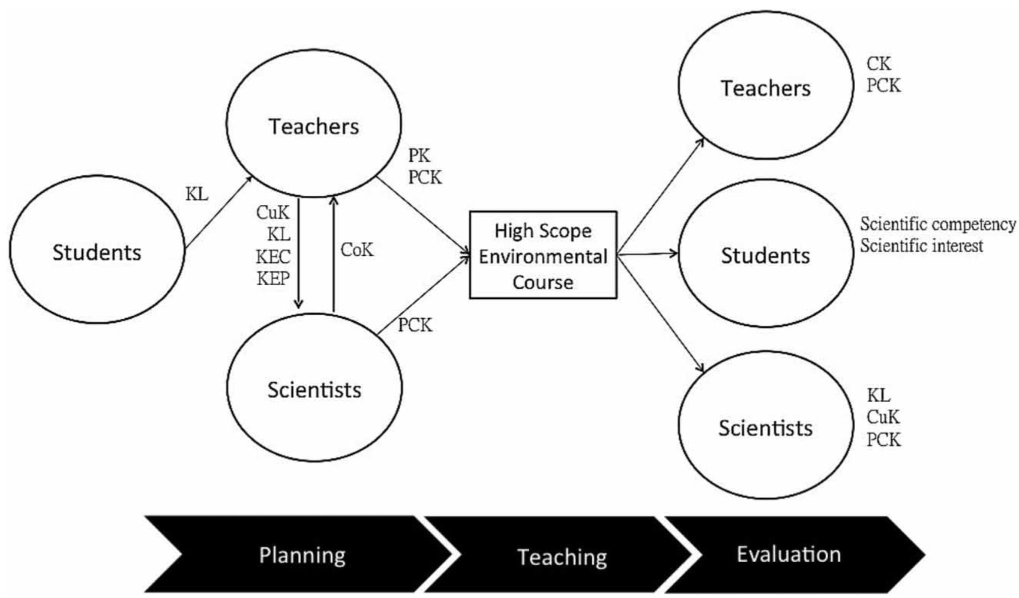

Figure 1. Scientist–teacher collaborative model (STCM). Note: The codes next to the arrows refer to the seven forms of teacher knowledge identified by Shulman: content knowledge (CoK), general pedagogical knowledge (PK), curriculum knowledge (CuK), pedagogical content knowledge (PCK), knowledge of learners (KL), knowledge of educational contexts (KEC), and knowledge of educational purposes (KEP)

plan, including the formulation of teaching objectives, selection of teaching content, and scheduling of teaching content; (2) teaching: co-develop teaching strategies and explore the use of large classes, discussion groups, or individual learning; (3) evaluating: include the assessment of teaching and learning outcomes as well as assessments of collaborative work.

The scientist–teacher collaborations formed in our study constituted two attributes. *First*, scientists and teachers co-plan and co-teach science lessons that are integrated into an existing educational program. Moss, Abrams, and Kull (1998) conducted a research in which students participated in a series of classroom projects over a school year that was designed to foster student scientist partnerships. However, findings showed that students' development of conceptual understanding of scientific research was limited, and conjectured that it could be due to a lack of a sense of partnerships by the students and the design of the scientist–student partnerships. The study conducted by Wurstner, Herr, Andrews, and Alley (2005) brought together scientists from national laboratory scientists and middle school teachers to design, implement, and evaluate a project. Their findings demonstrated improvement in students' conceptual understanding, problem-solving skills, and interest. *Second*, scientists and teachers collaborated to set up authentic research in science laboratories or include the use of professional tools and instruments. In a study conducted by Paris, Yambor, and Packard (1998), a six-week extracurricular program was designed that included hands-on biology activities in a laboratory setting in an elementary school. Their findings suggested significant improvement in students' interest in science and problem-solving skills, especially for girls. Lee and Butler (2003) designed an eight-week, inquiry-based weather curriculum for middle school students who allowed students to undergo inquiry processes and utilize tools used by meteorologists.

These two areas of research informed the formation of scientist–teacher collaborations in our study; however, the existing research all focused primarily on the students and thus the efforts made by the scientists and teachers were not described in great details and the benefits they obtained were not documented. Therefore, we aimed to make explicit the work scientists and teachers had done during the co-planning and co-teaching stages and invite them to examine the working of the partnerships as the course was undertaken, as well as to reflect as the course had ended. In essence, our study provides a holistic view of a STCM and its impact on all of its key stakeholders—students, teachers, and scientists.

Partnerships between scientists and teachers offer opportunities to strengthen the elements of effective science teaching. Shulman (1987) has identified seven forms of teacher knowledge: CoK, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge (PCK), knowledge of learners (KL), knowledge of educational contexts, and knowledge of educational purposes. The scientist–teacher collaboration constituted exchanges of these different kinds of knowledge of teaching; scientists and teachers play different roles, yet contribute their professional knowledge and practice in ways that complement each other. Teachers play the role of educational experts who have the comprehensive knowledge of curriculum, pedagogy, students, educational contexts, and educational purposes. Scientists play the role of content experts who simulate scientific inquiry and provide new insights into the nature of science in the real world. The STCM afforded a framework through which scientists and teachers could share and optimize their resources, values, goals, and efforts. The fulfillment of these elements of effective teaching aimed to yield benefits for students, as well as scientists and teachers, such as understanding of innovative teaching strategy and students' cognitive development for scientists, and understanding of authentic scientific inquiry and the latest scientific methods for teachers.

Within the framework of the STCM, three research questions emerged: (1) What effects does the STCM have on students' scientific competency and interest? (2) What factors contributes the changes in student interest? (3) What effects does the STCM have on improving teachers' and scientists forms of knowledge related to science teaching? Relevant literature reviews are provided in the following sections to delineate the focus of the study.

The Impact of STCM on Students

Our study hypothesized that the scientist–teacher partnerships would benefit the students in two ways. *First*, the scientists' participation would bring forth more innovative and challenging science content, that could cultivate the students' scientific competency. *Second*, the incorporations of scientists' introductions to cutting-edge research and invitations to their authentic research setting could stimulate the students' interests in science. Therefore, these hypotheses lead to a designed investigation on students' scientific competency and scientific interest, and the bases of these two constructs are supported by research studies as discussed below.

Scientific Competency

The existing literature suggest that scientist–teacher collaborations promote students' scientific competency, such as inquiry thinking (Lee & Butler, 2003), conceptual understanding, and problem-solving skills (Wurstner et al., 2005). Lee and Butler (2003) emphasized the importance of authentic activities in promoting students' inquiry learning. During their eight-week curriculum, students learned about weather with meteorologists and engaged in inquiry tasks similar to those practiced by the science community. Students' explanations that occurred in classroom inquiry were assessed by five essential features: (1) learner engages in scientifically oriented questions, (2) learner gives priority to evidence in responding to questions, (3) learner formulates explanations from evidence, (4) learner connects explanations to scientific knowledge, and (5) learner communicates and justifies explanations. Their findings found that the authentic activities helped students perform inquiry practices that are valued by the science community. Wurstner et al. (2005) established partnership between national laboratory and middle school to develop a hands-on, inquiry-based research project related to flash floods in southeastern Washington State. Although their study suggested that the project resulted in an improvement in students' conceptual understanding of earth science concepts and problem-solving skills, their data collection and analysis methods were not clearly presented to support such claims. In addition, these two studies did not use pretest evaluation to identify the baseline of students' progress, thus it was difficult to capture the growth of the students' competency and attribute such growth to the intervention that was taken.

Our study adopted the definition and theoretical framework of scientific competency established by the Organisation for Economic Co-operation and Development (OECD, 2010). Since 2000, OECD has been assessing 15-year-old students' performance on mathematics, science, and reading through the Programme for International Student Assessment (PISA). The PISA science assessment defines scientific competency as the ability to use scientific knowledge to recognize problems, explain scientific phenomenon, and make evidence-based conclusions (OECD, 2010). PISA scientific competency emphasizes on the preparation of basic abilities and skills for modern life. Students who participate in PISA assessment would be asked questions based on reading of short excerpts, emails, magazine articles, and statistical figures. This assessment method requires more procedural knowledge than factual knowledge because the students are given tasks that are contextualized in real-life situations. Thus, PISA does not assess students' proficiency in terms of school material but their decision-making process based on knowledge and skills.

Scientific Interest

The current literature also found that scientist–teacher collaborations promote students' scientific interest, expressed in positive attitudes toward and interests in science (Comeaux & Huber, 2001; Houseal et al., 2014; Ross et al., 2003), and motivation to engage in discussions about their learning (Huffman & Kalnin, 2003). Similarly, our study also hypothesized that teacher–scientist collaborations would promote students' scientific interest. However, we made a few attempts to overcome the limitations presented by these studies. Except the study by Houseal et al. (2014), the construct of interest used in the other studies was not based on robust or complex theoretical framework related to interest and lacked pretest–posttest design to determine the baseline of and shifts in interest. To capture more details of the change in interests than what was captured in the research by Houseal et al. (2014), we conducted by-unit posttests to understand how interest fluctuated in relation to the units within the course.

In our study, interest is referred to as a psychological state or a selective preference toward a particular domain of study (Ainley, Hidi, & Hillman, 2002). Interest can be further categorized into situational and individual interest (Renninger, Hidi, & Krapp, 1992). Situational interest is a short-term emotion that is stimulated by an individual or environment (Mitchell, 1993; Schraw, Flowerday, & Lehman, 2001). Individual interest is an internalized disposition that is stable and lasting (Renniger, 2000). To probe the sources that contribute to the changes in students' interest, situational interest is further categorized into triggered situational interest (TSI) and maintained situational interest (MSI). TSI illustrates the initial emotional experience that arises when an individual interacts with the context (Hidi & Renninger, 2006). MSI is when an individual makes a meaningful and deep connection with the context. When a connection is built upon the enjoyment of learning, it is defined as a maintained situational interest-feeling (MSI-F). When a connection is based on recognizing the value of learned knowledge in making sense of the world, it is defined as a maintained situational interest-value (MSI-V) (Schiefele, 2001).

The Impact of STCM on Teachers

In our study, the term *teachers* refers to members of the K-12 educational community, particularly high school science teachers who teach the subjects of biology, chemistry, and physics. Scientist–teacher collaborations bring teachers the benefits of updating CoK with recent scientific and technological developments, gaining an insight in the scientific inquiry, fostering positive attitudes toward science and scientists, and changing pedagogical strategies (Caton, Brewer, & Brown, 2000; Comeaux & Huber, 2001; Houseal et al., 2014; Wormstead et al., 2002). Research shows that collaborations with scientists affect teachers' understanding and teaching of science, which would ultimately improve students' scientific learning (Caton et al., 2000; Dresner & Worley, 2006), as students' study of science depends on the teacher's depth of scientific knowledge (National Research Council [NRC], 2007, p. 296). However, scientific knowledge is not limited to just understanding scientific content, but also the process of scientific inquiry (NRC, 1996). The STCM aimed to provide teachers with the latest developments in scientific research and allow them to experience the process of scientific investigations, and consequently enhance their confidence and enthusiasm toward science education.

The partnership of scientists in science education is increasingly important, especially for the professional development of teachers. Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) suggested that the key to quality professional development is to provide teachers the opportunity to work with scientists. Additionally, collaborative teaching provides teachers more opportunities to learn from each other (Rathgen, 2006), improves knowledge in the content, teaching methods, and curriculum development (Huffman & Kalnin, 2003), and generates synergy with other teachers (Hoogveld, Paas, & Jochems, 2003). In consequence, the teachers who participate in collaborative teaching recognize the meaning and importance of professional growth (Moran, 2007).

The Impact of STCM on Scientists

In our study, the term *scientists* refers to members of the scientific research and practice community, including higher education faculty, postdoctoral fellows, graduate students, and other professionals in the science and technology-related institutions. Through collaborations with teachers in communicating science to the K-12 students, scientists reap the benefits of improvement in communication and pedagogical strategies, and better understanding of students' cognitive development (Caton et al., 2000; Donahue, Lewis, Price, & Schmidt, 1998).

Scientists command and create scientific knowledge and use scientific methods in their professional lives. In theory, they should be the ideal partner for high school science teachers. However, inviting university professors or scientists to teach in K-12 schools is difficult as they focus on very specialized areas of scientific research and often have limited experience or training in teaching. Moreover, science differs from other subjects in that some prerequisite knowledge is necessary in order to fully understand new scientific concepts, and it involves technical language and knowledge which is vastly different from those used by students.

Clover (1997) believes communicating scientific knowledge is like storytelling, describing a person's past experiences through which awareness, values, attitudes, and actions were generated; however, this method is different from the traditional method of teaching. Scientists' technical knowledge is normally higher, logic is based more on cause and effect, and narrations are more hierarchical. Scientists' challenge of communicating science is to situate complex scientific concepts in real-life contexts, because scientific concepts are produced by controlled conditions and rigorous processes; whereas real-life examples are open for various conditions that cannot be easily simplified into a model. Therefore, how to connect students' experiences and knowledge has become a major challenge (Bardwell, 1991). As such, the STCM allowed scientists the opportunity to better communicate their research to young audience by integrating the educational theory and practice provided by the teachers (Dolan, Soots, Lemaux, Rhee, & Reiser, 2004).

Methods

Research Design

Mixed methods research (Creswell & Clark, 2007) was used for this study. Qualitative methods of interviews were used to understand the impact on the teachers' and scientists' science teaching. A quasi-experimental design was used to understand the impact on students' scientific competency and scientific interest. At the beginning of the semester, both the experimental and comparison groups took pretests to measure their scientific competency and interest. During the intervention, the experimental group took five by-unit interest surveys that only included items on scientific situational interests, and keywords were changed accordingly to the theme of each unit. At the end of the semester, both the experimental and comparison groups took posttests of scientific competency and interest that were identical to the pretests.

Intervention of the High Scope Environmental Course

The High Scope Environmental (HSE) course was implemented in one public high school in the fall semester of 2012. In addition to the two hours of biology course that both the experimental and comparison groups had to take in a week, the experimental group took two to four hours of the HSE course. The most distinguishing feature of this course was the collaboration of teachers with scientists using the STCM. The HSE course was co-planned and co-taught by eight scientists from the disciplines of molecular immunology, aquatic invertebrates, microbial physiology, infectious tropical disease, organic solar cells, organic optical materials, data processing, and laser micro/nanoengineering, and four science teachers from the disciplines of biology, chemistry, and physics. In the STCM, to co-plan the course, teachers communicated with the scientists before the start of the semester. To prepare the students for scientist lectures or laboratory visitation, teachers introduced technical terms and background information to the students to bridge the gap between the professional content and the existing high school curriculum. To help the scientists prepare their lectures or laboratory visitation, teachers provided the description of students' prior knowledge, allowing the scientist to adjust the content accordingly.

There were five units in the HSE course: (1) introduction to the environment in Taiwan, (2) effects of environmental pollution, (3) concepts and applications of sustainability, (4) organic optical technology, and (5) solar energy technology. The content of the five units is summarized in Table 1. All five units integrated concepts of advanced science and technology, three units had role-playing activities to activate the affective aspect of learning, and two units had laboratory visits to bring students closer to authentic science research. The students who participated in this study were freshmen, 15–16-year-olds who are in their first year in a 3-year high school. There were six classes among the entire grade of freshmen, and we picked two classes that were comparable in their prior academic performance to be the experimental and comparison groups. There were a total of 35 students in the experimental group and 34 students in the comparison group.

Instrument 1: Scientific Competency

For the scientific competency test for this study, 15 items consisting of multiple choice, true-and-false, and open-ended questions were selected from the items on the PISA 2006 science assessment, which were constructed by the OECD and translated by professors in Taiwan (OECD, 2007). Each item was scored as 10 points for full credit, 5 points for partial credit, and 0 points for no credit. The full score for the entire assessment was 150. The measures of validity and reliability were all acceptable. According to Rasch's analysis (1960), the infit mean square error values of each item were between 0.95 and 1.18. The item separation reliability for the whole test was 0.95.

Instrument 2: Scientific Individual and Situational Interest

Interest surveys used in this study included two scales of individual and situational interests and an open-ended question. The scale of individual interest referenced Mitchell's (1993) individual interest scale and Schiefele's (2001) subscales of

Table 1. Summary of five units of the course

Unit	Topic	Novel topic	Role playing	Lab visit	Scientist	Teacher
1. Introduction to the environment in Taiwan	Environment and ecological system in Taiwan					J
	Relationship between pollution and Melioidosis	✓	✓		A	
2. Effects of environmental pollution	Pollutions in Taiwan and the health of the community					J
	A simulation game about the effect of overfishing	✓	✓			J,K
	Water pollutions and aquatic preservation in creeks, rivers, and ocean	✓			B	
3. Concepts and applications of sustainability	A simulation of public hearing on local pollution		✓			J,K
	Environmental pollutions and bioremediation	✓			C	
	Prevention of dengue fever in the tropics	✓			D	
4. Organic optical technology	Theory of optical technology	✓				L
	Photovoltaic system energy conversion	✓				L
	Theory and application of organic optical technology	✓			E	
	Visit an organic optical technology research laboratory	✓		✓	F	
5. Solar energy technology	Creative applications of solar energy in daily lives	✓				M
	History of solar energy research and applications in architecture	✓			G	
	Visit a design laboratory that uses solar energy	✓		✓	H	

feeling related and value related. The scale of situational interest referenced the Measuring Situational Interest in Academic Domains scale developed by Linnenbrink-Garcia et al. (2010) that consists of three subscales of TSI, MSI-F, and MSI-V. Two science education researchers, two primary school teachers, and one secondary school teacher checked for content validity and then made sure that the translated items reflected the original concepts by pretesting 144 primary and secondary school students. We used principal component analysis to collect the common factors, and used varimax to execute the orthogonal rotations. From that we got five factors, and the cumulative explained variance was 74.26%, which means that the questions still reflected the same concepts. Analyses of student interest data collected in this study indicated internal consistencies for individual interest items (Cronbach's alpha = .88) and for situational interest items (Cronbach's alpha = .61). Students were asked an open-ended question at the end of each unit, 'What is the main reason that you become interested in the activities in this unit?'

Interview 1: Teachers

We conducted a semi-structured teacher interview after each scientist taught a lesson by asking three questions: (1) How do you think the lesson went? (2) Do you think the lesson fulfilled the teaching objectives? (3) How would you improve the lesson if you were to teach it again? At the end of the 18 weeks, teachers were interviewed individually on their perceptions of the entire semester. Questions related to four aspects: (1) collaborations with scientists during the co-planning phase, (2) the impact of the STCM on their teaching, (3) suggestions for changes in the curriculum, and (4) perceptions of the STCM.

Interview 2: Scientists

We conducted a semi-structured scientist interview after a lecture or a laboratory visit by asking the same three questions as were asked in the teacher interview, along with two additional questions: (1) Did you make any adjustments to the lecturing content to meet the level of high school students, or use any strategies to help the students understand better? If any, please explain. (2) Was the lecture different from your other lectures in the past? If yes, how so?

Data Collection and Analyses

Teachers scored each student's answers in scientific competency instrument according to the PISA scoring rubric with the outcomes of 0, 5, or 10 points. To ensure internal continuity for scoring, this study asked a different researcher to score half of the original answers randomly selected from already graded students (Hruschka et al., 2004). Coding agreements were found in 89% of the selected cases, and inconsistencies were discussed.

The interest instrument was used as a pretest on the incoming freshmen's prior science learning experience in junior high school. The context of the interest instrument was modified according to the science learning experience that occurred during the 18 weeks of the HSE course, and then given as a posttest at the end of the 18 weeks. Covariate analysis was conducted to explore the impact of STCM on scientific competency and interest by studying the differences in the two covariates of scientific competency and interest between the comparison and experimental groups.

Coding schemes were constructed for the qualitative data collected from the open-ended question on the source of student interest and the teachers and scientists interviews using a constant comparison method (Strauss & Corbin, 1990). If a statement constituted difference constructs, multiple codes were attributed. Statements were carefully and independently coded by three well-trained research assistants. Coding agreements were found in 90% of the statements.

Results

Research Question 1: What Effects if Any Does the STCM Have on Students' Scientific Competency and Interest?

The Analysis of Covariance (ANCOVA) results from the scientific competency instrument are given in Table 2. The homogeneity of regression values for the two groups were not different. The posttest difference between the groups achieved significance ($F_{(1,\ 66)} = 5.20$, $p < .05$), with an effect size (ES) of .073. According to Cohen's (1988, p. 274) definition, the small, medium, and large ESs for an F-test are .01, .06, and .14, respectively. This shows that the intervention had a medium effect on students' scientific competency. The comparison in Table 2 shows an adjusted posttest mean score of 121.50 for the experimental group, which is higher than the 114.63 score obtained for the comparison group.

The F-test appears in the separate ANCOVA computed on the two types of interest scores in Table 2. The homogeneity of regression values for the two groups were not different. The ANCOVA was then conducted to evaluate the measures in the individual interest and situational interest scale. There were differences between the two groups which reached significance for the individual interest scale ($F_{(1,\ 66)} = 85.69$, $p < .05$) and the situational interest scale ($F_{(1,\ 66)} = 12.52$, $p < .05$). A large ES

Table 2. The ANCOVA of scientific competency and interest

		Group	Pretest Mean (SD)	Posttest Mean (SD)	Posttest Mean (SE)	F	η^2
Competency	Overall score	Experimental	112.14 (12.96)	122.57 (8.07)	121.50 (2.09)	5.20*	0.073
		Control	106.62 (17.04)	113.53 (17.51)	114.63 (2.12)		
Interest	Situational interest score	Experimental	46.40 (5.77)	46.46 (7.33)	45.359 (1.34)	12.52*	0.159
		Control	42.53 (5.83)	38.71 (9.31)	39.836 (1.36)		
	Individual interest score	Experimental	31.23 (5.16)	33.23 (4.26)	31.804 (0.59)	85.69*	0.565
		Control	27.65 (4.21)	28.32 (5.78)	29.790 (0.60)		

Notes: $^{*}p < .05$.

SD, standard deviation; SE, standard error.

existed between the posttest scores of the two groups on the situational interest scale ($\eta^2 = .159$), and a large ES existed for the individual interest scale ($\eta^2 = .565$).The adjusted posttest scores represent the posttest scores adjusted according to the differences in pretest scores between the two groups. The results of ANCOVA confirmed a trend for students in the experimental group to have more individual interest (adjusted posttest mean = 31.804) than students in the comparison group (adjusted posttest mean = 29.790). Similarly, the results showed the increase in the situational interest scale (adjusted posttest mean = 45.359 for the experimental group and 39.936 for the comparison group).

Some by-unit differences were found in three dimensions of situational interests in Table 3. For the 'introduction to the environment in Taiwan' unit, the mean difference between the pretest and posttest for TSI, MSI-F, and MSI-V increased by 2.05, 2, and 1.38 points, with the ESs of .79, .32, and .59, respectively, and all reached the significance level of $p < .05$. For the 'effects of environmental pollution' unit, the mean difference between the pretest and posttest for TSI, MSI-F, and MSI-V increased by 1.65, 2.24, and 1.42 points, with the ES of .63, .90, and .61, respectively, and all reached the significance level of $p < .05$. For the 'concepts and applications of sustainability' unit, the mean difference between the pretest and

Table 3. *T*-tests of by-unit difference in three dimensions of situational interests in the experimental group

Unit		TSI	MSI-F	MSI-V
1. Introduction to the environment in Taiwan	d	2.05	2	1.38
	t	4.86	3.79	3.37
	p	.000*	.001*	.002*
	ES	.79	.32	.59
2. Effects of environmental pollution	d	1.65	2.24	1.42
	t	3.59	4.14	3.23
	p	.001*	.000*	.003*
	ES	.63	.90	.61
3. Concepts and applications of sustainability	d	1.11	2.08	1.27
	t	2.45	4.07	3.17
	p	.020*	.000*	.003*
	ES	.42	.83	.55
4. Organic optical technology	d	−0.11	1.19	0.19
	t	−0.25	2.19	0.4
	p	.806	.035*	.691
	ES	−.04	.48	.08
5. Solar energy technology	d	0.03	1.38	0.86
	t	0.063	2.35	1.78
	p	.95	.024*	.084
	ES	0.01	0.55	0.37

Notes: *d*, difference between pretest and posttest; TSI, triggered situational interest; MSI-F, maintained situational interest-feeling; MSI-V, maintained situational interest-value; ES, d/SD_{pre}.

*$p < .05$ (d.f. = 36).

posttest for TSI, MSI-F, and MSI-V increased by 1.11, 2.08, and 1.27 points, with the ES of .42, .83, and .55, respectively, and all reached the significance level of $p < .05$. The last two units only showed significant increases in the feeling aspect of students' situational interest, MSI-F. For the 'organic optical technology' unit, the mean difference between the pretest and posttest for MSI-F increased by 1.19 points (ES = .48), with a significance level of $p < .05$. For the 'solar energy technology' unit, the mean difference between the pretest and posttest for MSI-F increased by 1.38 points (ES = .55), with the significance level of $p < .05$.

Research Question 2: What Factors Contribute the Changes in Student Interest?

We further investigated the sources of situational interest. Five sources emerged from the students' responses to the open-ended question about the source of their interest (Table 4). The frequency of each source was counted for each unit (Table 5). The main source of students' scientific interest was gaining of new knowledge (mean = 18.8), followed by applying knowledge to solving problems (mean = 13.6), resonating with teaching methods and materials (mean = 7.2), enjoying learning (mean = 4.8), and appreciating the value of knowledge (mean = 4.8). Note that for the last two units, no students mentioned anything about appreciating the value of knowledge.

Research Question 3: What Effects if Any Does the STCM Have on Improving Teachers' and Scientists Forms of Knowledge Related to Science Teaching?

Content knowledge. In the teacher interview, all four teachers mentioned that they gained new knowledge in science and technology through the STCM. At the outset

Table 4. Coding keys and examples of sources of student interest

Code	Label	Example
C1	Resonating with teaching methods and materials	The explanations and the activities are very appealing, so I naturally find it interesting
C2	Gaining of new knowledge	It is when I learn something I did not know that I became interested in bioremediation, something that could be useful in the future
C3	Applying knowledge to solving problems	In response to a global pollution and burning out of natural energy, I became interested in solar energy. I see many applications of solar energy in this course
C4	Enjoying learning	Using another species to control the growth of another species is very interesting. I could also see the images of predation. No matter how I see it, I find it interesting. I am just interested in living species
C5	Appreciating the value of knowledge	Every human action could affect ecological balance, no just this, some of these hazardous chemicals go through cycles and affect humans indirectly, and therefore, we should value environmental education and live in peace with nature

Table 5. By-unit frequency and mean of sources of student interest

Unit	C1 Teaching methods and materials	C2 New knowledge	C3 Problem-solving	C4 Enjoying learning	C5 Value of knowledge
1. Introduction to the environment in Taiwan	15	13	10	3	13
2. Effects of environmental pollution	15	20	7	3	8
3. Concepts and applications of sustainability	4	22	23	5	3
4. Organic optical technology	1	21	11	5	0
5. Solar energy technology	1	18	17	8	0
Mean	7.2	18.8	13.6	4.8	4.8

of the study, all teachers informed their themes and educational goals for each unit to the scientists, and the scientists decided the specific lecture topics and provided materials for teachers to prepare activities around their lectures. The HSE course differed from the typical high school courses in that it incorporated new technologies. Therefore, the teacher gained updates in science development and related resources when they interacted with the scientists and listened to their lectures with the students.

Pedagogical content knowledge. All the teachers mentioned that by observing the scientists teaching, they learned new concepts, methods, examples, videos, and photos that could be used in their future teaching. As teacher M mentioned, 'The scientist had an impact on this HSE course and helped my planning for the other course; there are some examples I can use.' The teaching methods scientists used to spark student interest, diversify education, and encourage high-level thinking provided a model for teachers to emulate. As teacher K mentioned,

> The scientist communicated very clearly and designed a few questions to stimulate students' thinking … those were really good questions that could guide the students. I think I need to continue to learn this because traditional biology classes lack this kind of design.

After the lectures, most scientists were willing to share with teachers the slides, videos, or websites they used in class. Thus, the lecture content becomes ready to use teaching materials that can save the teachers some time from creating and searching for teaching materials. As teacher J mentioned, 'I could use the examples, PowerPoint slides, and pictures in my own teaching.'

Knowledge of learners. The KL had two exchanges in the STCM model. *First*, it occurred in the co-planning stage from the teachers to the scientists. The four teachers had to co-plan with eight scientists before the course. The teachers knew that Scientist B and D had previous knowledge and experience of communicating to the youth or public; and, the teachers had heard Scientist C explained his work and felt that his way of communication was appropriate for high schools students. However, for the other five scientists, the teachers had to directly tell them what these students had learned in science classes before high school, how these students are more responsive to concrete examples instead of abstract theories, and how these students are more engaged in lectures that pose questions for them to answer and discuss. *Second*, another exchange of the KL occurred in the co-teaching stage, when the scientists had a direct contact with the students. From the interactions with students during lectures, the scientists gained first-hand insights in students' thinking. When evaluating the success of the lecture, scientists could tell if students understood the content from their reactions. In particular, the questions students asked showed their interest in the topic and depth of understanding. Scientist C mentioned, 'I was very happy about the questions they asked today. Maybe I can adjust a bit more and add some more difficult stuff for them to think about.' Students' responses to the questions scientists posed also helped the scientists to gauge students' level of understanding. Scientist B believed, 'I think most students take away some information, and the conversations I had with the students and their responses all aligned with what I intended to develop from the questions.' Scientist A thought, 'I think the outcome and their reactions were very positive. From everything they have absorbed and shown until now, you can see that the students sufficiently understand the content.' After learning about what stimulated students' interest, Scientist D reflected, 'I might reduce reading excerpts and add more explanations to videos or topics that students are more interested in, in order to push further on their thinking.' Scientist E noticed that the students' reaction was 'okay' and reflected that the materials presented probably required some time for the students to absorb. He suggested that some basic knowledge needed to be established prior to his lecture and can be done through providing readings.

Curriculum knowledge. After 18 weeks of the HSE course, scientists recognized the importance of understanding the students' background information and the existing school curriculum when collaborating with teachers. This information would help the scientists to scaffold necessary foundations for students to connect to the new concepts. Scientist B mentioned, 'I hope to know some more about the other existing curriculum so I could think of ways to connect the content with the goals and framework of the existing curriculum so they could get more out of it.'

Particularly, scientists F and H, who organized the two laboratory visits, found it challenging to adjust teaching in authentic research setting. Explaining how the scientific instruments work without using technical terms was very difficult for scientists. Although theories can be simplified and explained using real-life examples, it is a challenge for scientists to find common terms to explain the components, function, and operation of instruments.

> The slides used in the curriculum still need to be simplified, and the topics included in the curriculum still needs to be clearer … these need to be changed into materials for high school students or an average person. Otherwise, the audience might get stuck at a certain point and unable to continue. That means the teaching material isn't seamless enough … if we want to get students to understand something that complex, we've already filtered out a lot, but what remains still has some technical aspects. (Scientist F)

Logistically, laboratory visits are more complicated than classroom lectures in that there are details of logistics that need to be arranged beforehand. Scientist F suggested, 'We might need to better coordinate the logistics, including whether to give the demonstration or the lecture first, what should be the first topic in the lecture, then we would have a clearer agenda.' Scientist H suggested, 'It was a little difficult to keep track of time … perhaps because we split into four groups [for rotation] and the time spent with each group was slightly different, so students had to wait for the previous group to finish.' If students are to be given an opportunity to perform a hands-on experiment or operate an instrument, scientists suggested reducing group size and allotting ample time for exploration.

> If we demonstrate the handling of the instrument, or even allow students to press some buttons, they'll be more interested, but there can't be too many people, the clean room is pretty small, could fit just six or seven people. For time, there is a lot of equipment in the clean room, maybe will need 30-40 minutes. I might add some things for them to do, like some small experiments … If I demonstrate personally, it'd probably be better if there were just five people and the explanation and demonstration would take about 30 minutes. (Scientist H)

Pedagogical content knowledge. The scientists described how successful science teaching relies on making abstract scientific knowledge concrete, relating it to life experiences, and eliciting student thinking through problem posing. Scientists' distinct lecture style can also increase students' interest in learning. Each lecture usually begins with a real-life example or a socio-scientific issue to connect the individual to topic.

> It's hard for high school students to understand the molecular structure of [Melioidosis] was like before, because they haven't learned this, so I started from a social issue, students find newspapers and news comprehensible, so I start from that angle. (Scientist A)

Scientists also used pictures or videos to facilitate the understanding of abstract concepts, reduce explanations, and increase practical knowledge.

> My slides have more examples to help high school students understand. For example before I introduce a theory, I'd like to give an example to explain. Students relate more to real-life examples, so when you give her an example, she'll know immediately what you're talking about. And then from there, you can move into the theory. This way, students will be able to understand easily. (Scientist C)

Making life demonstrations of experiments may not be feasible or safe for high school students, and thus videos can be used to show the research process.

> Students will lose their focus if the video is longer than ten minutes. If we want the video to supplement teaching, we should explain while the video is playing. The best method is to rewind and watch a part that includes some scientific theories because we can't demonstrate it in class and the video is a good demonstration. The explanation in the video may be too dry, but they'll be able to understand better with our explanation. (Scientist G)

During lectures, scientists posed questions to motivate student thinking. The discursive process of questioning and answering allowed the scientists to better understand students' grasp of the content. Additionally, some scientists engaged students with storytelling, pictures, videos, speech tones, for them to be immersed in the topic and become a part of the story as they contemplated the questions.

> We try to use real pictures and real places along with storytelling so our students can understand through both oral communication and pictures. When we give a lecture, we need to do both show and tell, that's the only way to deepen the audience's knowledge. (Scientist D)

Discussion and Conclusions

The findings demonstrate that the partnerships built between scientists and teachers in the STCM positively affect learning and teaching in high school science education. Not only did the students benefit from the participation of scientists, but the teachers who helped to facilitate the partnerships also developed some essential elements of effective science teaching that they could take with them to their other classrooms, as well as the scientists who attempted to teach a younger audience also developed some essential elements of effective science teaching upon which they could build to continue future partnerships with the same high school or other high schools. As future research, it would be worthwhile to investigate the accumulative effects of effective science teaching long-term partnerships between scientists and teachers can create.

STCM Develops Students' Scientific Competency

The findings in our study suggest that the use of STCM had a medium effect on students' scientific competency. In the HSE course, the scientists introduced new scientific concepts with real-life examples and socio-scientific news, and the teachers incorporated role-playing opportunities for students to analyze the imminent damage pollutions or diseases may cause to the environment and the people. As what Bullough, Young, Birrell, Cecil, and Winston (2003) indicated, teachers working in collaboration can give students a different perspective in making sense of science, stimulating their creative and critical thinking skills.

STCM Develops Students' Scientific Interests

The findings in our study suggest that the use of STCM had a large effect on students' scientific individual and situational interests. Similar effect on students' interest was also found in the study on collaborations with novice and experienced teachers conducted by Roth, Tobin, Carambo, and Dalland (2006). With a further investigation with qualitative data, we found that the first two main sources of student interest were the gaining of new knowledge and being able to apply such knowledge to solving problems in their lives. The sources may be tied to the scientists' prevalent use of real-life examples to explain new scientific concepts and the emphasis of their relevance to students' lives. Discrepant or novel stimuli have the ability to arouse student interest (Palmer, 2004) and the connection between school science and real-life experiences prevent the students from perceiving science as boring or distant (Lin, Hong, & Huang, 2012). The large effect on individual interest would be due to diverse learning opportunities provided in the 18-week long of interaction with scientists, in learning new scientific concepts, discussing the impact of pollutions and new science and technology on the local environment, experiencing different teaching methods, seeing the scientists demonstrating experiments (Huffman & Kalnin, 2003). An intervention study conducted by Lin, Lawrenz, Lin, and Hong (2012) also found that short-term situational interest triggered by specific features, such as those in STCM, can transform into a well-developed individual interest.

When combining the analysis of the by-unit differences in three dimensions of situational interest (Table 3) and the by-unit sources of student interest (Table 5), we found two patterns. *First*, the first three units showed significant increase in all three dimensions of situational interest in Table 3. What these three units shared in common that is different from the last two units was that they incorporated role-playing activities. After the activities, the teacher or scientist prompted the students to reflect on the relationship between environmental problems and human actions. Difference between the first three units and the last two units was also found in the frequency of two sources of student interest, teaching methods and materials (C1) and value of knowledge (C5), as given in Table 5. The findings may suggest that the teaching method of role modeling appealed to the students and the reflective nature of such activities allowed them to see the value of their learning.

Second, the last two units did not show significant differences in TSI and MSI-V in Table 3. The distinguishing feature of these two units was the new technology introduced in the laboratory visits. Students also rarely mentioned teaching methods and materials (C1) and value of knowledge (C5) as sources of interest in Table 5. Students mentioned their sources of interest come from gaining new knowledge (C2), applying knowledge to solving problems (C3), and enjoying learning (C4). Even though students had learned new knowledge and its application, and even enjoyed the learning process, they did not find the teaching methods and materials engaging, their situational interest could not be triggered. This could be due to the difficulty students had in understanding the technical terms used to describe and demonstrate instruments in the laboratory, leading to ineffective communication. The instruments themselves may be novel and have potential to solve environmental problems, but the teaching methods used to introduce them need to be improved to trigger the students' interest and eventually understanding the real value of knowledge. Our findings do not depreciate the value of laboratory visit, but acknowledge the logistical and communicative challenges that need to be addressed in order for K-12 students and lay people to understand the work of scientists in the authentic setting. It is difficult to appreciate the value of new science or technology, the 'why', if it's fundamental concepts and processes, the 'what' and 'how', are not communicated through appropriate methods.

STCM Develops Teachers' Content Knowledge and PCK

For science teachers, who face diverse study bodies in the midst of rapidly changing technology, teaching becomes challenging and at times frightening. Collaborations with scientists provided the professional development that the science teachers needed to keep up with the new science and technology. The teachers revealed in the interviews that they were able to learn new knowledge through the examples, videos, and discussions guided by the scientists. Some of what the teachers learned could be applied directly and immediately in their own classrooms. The implementation of the newly gained knowledge and methods will in turn increase their teaching confidence.

STCM Develops Scientists' KL, Knowledge of Curriculum, and PCK

There has been a gap between the science imagined by the students and the science practiced by the scientific community. Interactions with scientists can broaden students' views on science and help them understand that science is intimately related to daily lives. However, the challenge scientists face is communicating complex scientific knowledge using a language appropriate for high school students and a context relevant to their experiences (Bardwell, 1991). At the co-planning stage, teachers helped scientists understand the cognitive development of these high school students, the background knowledge these students had accumulated in their previous years of study. Teachers also helped to preview the materials prepared by the scientists to predict whether the students would be interested or be able to understand. Teachers' contribution of their KL in the co-planning stage guided the scientists in preparing for the co-teaching stage. During the co-teaching stage, scientists got first-hand information on student engagement through their questions, their responses to the questions posed by the scientists, facial expressions, and level of participation. In addition to the informal assessment of student understanding, scientists could get specific information on a survey to see how the students think they understand the topics covered in the lecture.

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