GK–12 Partnership: A Model to Advance Change in Science Education

NANCY STAMP AND THOMAS O’BRIEN

Sufficient quality and quantity of science education at the elementary-school level is the key to developing science literacy and inspiring students about potential careers in science. We collaborated with a school district to develop 5E (engage, explore, explain, elaborate, evaluate) teaching cycles that matched the state and district curriculum guidelines. The 5E teaching cycle is a hands-on/minds-on, inquiry-based method that is effective at any level of instruction, especially for challenging misconceptions. Teams of teaching fellows (graduate students in the sciences) and teachers implemented the instructional units. Their training was fine-tuned, for example, by using a classroom teaching-observation rubric and information about the teachers’, teaching fellows’, and students’ attitudes toward science education. The most significant result was that, in addition to the teachers becoming more comfortable with and adept at teaching science and the fellows improving their communication skills, the fellows understood the value of linear conceptual development in science curricula and their ability to facilitate that as teachers.

Keywords: elementary science education, 5E teaching cycle, graduate education, misconceptions, science literacy

Elementary science is a local district, state, and national weak link in the continuum of K–16 (kindergarten through college) science education. To address that, core curriculum guidelines are calling for emphasis on “a hands-on and minds-on approach to learning” and for future assessments that will test students’ ability to explain, analyze, and interpret scientific processes and phenomena (NYSED 2000). But implementing such standards-based recommendations poses a special challenge, for several reasons. First, K–6 science programs are limited in terms of teacher training and classroom resources. Generalist teachers in grades K–6 have substantially weaker science background than science specialist teachers in grades 7–12. Schools at grades K–6 also have more limited science equipment, supplies, and budgets, and have a history of shortchanging science in their budgeting and curriculum decisions. These constraints are especially problematic because the elementary-school years are when children often make fundamental decisions that influence their career track (NRC 1990).

Second, because commercial textbooks are aimed at the mass market and so try to cover a little bit of everything in each grade, they are neither conceptually nor developmentally appropriate in terms of the sequencing and breadth or depth of concepts covered, relative to the National Science Education Standards (NAS 1995) recommendations and research. Specifically, what is lacking in commercial textbooks and school curricula are conceptually linked and logically sequenced lessons that (a) align with state standards and school-district curriculum maps; (b) focus on addressing preexisting misconceptions that have been documented by researchers as being especially resistant to change (Bransford et al. 1999); (c) are designed around a teaching cycle that utilizes and develops multiple intelligences (Armstrong 1994); (d) integrate science with English language arts, mathematics, and social studies, which elementary teachers tend to be more comfortable with teaching (AIMS 1994); and (e) are developed with input from and tested by local teachers to ensure that they match students’ needs. Fortunately, between commercial textbooks, videos, CD-ROMs, and Web sites, a range of high-quality, inquiry-based science activities are available for inclusion into more standards-based instructional sequences.

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Third, the K–6 science curriculum is in a state of flux within individual school districts (including our partner, Binghamton City School District), in New York State, and across the nation. District-level K–6 science curricula typically exist, at best, as draft curriculum outlines or “maps” that suffer from a lack of research-informed articulation at the intergrade and intragrade levels, and from a lack of sufficient details about how to address the state-mandated concepts and skills at the classroom level. As a result, K–6 science instruction is typically sparse and uneven, varying from teacher to teacher, from grade level to grade level, from building to building, and from district to district. Although the science textbooks recently purchased by our district partner came with some much-needed basic science equipment and supplies, the typical elementary teacher had neither the science knowledge nor the pedagogical knowledge to use these materials to put flesh on the bare bones of the district’s draft curriculum maps.

Thus, a partnership between elementary-school teachers who are experts in children’s learning and a university that is rich in science content, process, personnel, and equipment has great potential. Elementary–school teachers can provide pedagogical expertise and approaches suitable to the age of their students and to the diversity represented in their classrooms. In a complementary fashion, as trained resource aides, graduate teaching fellows can provide up-to-date scientific information and engaging activities to develop concepts, habits, and skills necessary for future study and work in science.

The NSF GK–12 program at Binghamton University
The National Science Foundation (NSF) Graduate Teaching Fellows in K–12 Education (GK–12) program is designed to strengthen ties between K–12 and postsecondary education. In the NSF GK–12 program at Binghamton University, State University of New York, graduate students who are training as research scientists serve as part-time resource aides for K–12 teachers instead of working as teaching assistants for undergraduate courses. The graduate students are provided special training and then paired with teachers in a school district. Binghamton University’s district partner, the Binghamton City School District, faces a variety of socioeconomic challenges, such as a relatively high proportion of lower-income students (i.e., those receiving free or reduced-fee lunch) and of those with English as a second language. Our program focuses on grades 3–6 and on graduate students with baccalaureate degrees in biology, chemistry, earth sciences, engineering, and physics.

Why would students seeking careers in research want to participate in this program? Part of becoming a scientist is learning to communicate with other scientists, which often requires the use of technical words and abstract concepts (Kenny et al. 1998). But that becomes a stumbling block when trying to communicate to nonscientists. A year or two working in K–12 schools helps these future scientists hone their communication skills (Mervis 1999). They are better able to explain their work to the public, to students of any age, and to people in industry and government. Furthermore, many graduate students receive little or no training in science education when they are teaching assistants for university courses, but this program provides specific training in science education that applies at any level.

Our approach
The conceptual focus of the program was on developing an educational culture that emphasizes using 5E teaching cycles of instruction, with an emphasis on identifying and challenging students’ preconceptions and misconceptions, while testing and refining the 5E cycles using the research-lesson approach. The “5E” in “5E cycles” refers to a sequential format of activities that encourage students to “engage, explore, explain, elaborate, and evaluate,” and “cycle” refers to the need to revisit concepts within and across cycles (Bybee 1993). The term research lesson refers to the idea of developing and continually refining a series of inquiry-based lessons through observation, assessment, and shared reflection (Stigler and Hiebert 1999).

The 5E-cycle instructional unit
Our objective was to develop a linked series of 5E cycles for each instructional unit. The 5E approach is particularly effective for challenging children’s misconceptions and giving them the opportunity to reconstruct their ideas. Typically the “engage” phase includes a preassessment and a discrepant event (i.e., a surprising or puzzling demonstration of a scientific phenomenon, with an outcome that students are unlikely to expect) to challenge students’ misconceptions (Dreyfus et al. 1990). Demonstrations and hands-on activities can occur in each phase. The “evaluate” phase typically requires application and may reuse the preassessment survey as a postassessment. The 5E cycles stress habits of mind as well as content. To date, we have developed about 18 usable drafts of 5E units that match the curriculum maps and state standards for each of grades 3–6.

As an example of the type of activities and the linearity of conceptual development, here is an abbreviated version of how the 5E sound unit for grade 3 works. The unit begins with the “engage” phase, using “What Was That Sound?” (a bingo game based on identifying sounds from “spectacular sound effects” CDs), “Shake, Rattle and Roll” (identifying items in a closed container by sound), or both. The “explore” phase begins with “What Is Sound?” This activity pairs students, who take turns as the speaker (with hand on larynx) and the observer, for the purpose of describing and discussing what they are learning about sound. It is followed by “Rock and Roll Puffed Cereal”: puffed cereal in an aluminum pan on the speaker of a boom box (with the speaker lying horizontally), with the sound gradually increased, further illustrating the relationship of sound and vibration. The “explain” phase includes discussion, introduction of terms, and additional demonstrations, such as dominoes arranged like the spokes of a wheel, so that a tennis ball dropped in the center causes the dominoes to fall outward in all directions like an energy wave from a sound source. The “elaborate” phase includes...
“Underwater Sounds,” for which students half-fill a plastic ziplock bag with water, place an ear against it and a ticking clock on the other side, and plug the other ear with a finger. In addition, a demonstration with a tuning fork shows that a vibrating fork in water causes water to move (i.e., molecules to vibrate). In the “evaluate” phase, student teams build and test their own instruments (e.g., flute, drum, one-string guitar) and explain how sound is generated from them. After taking this unit, 21 percent fewer third graders (n = 80) reported the misconception that sound is made when an object vibrates (in fact it comes from an object creating vibrating air, which in turn causes a receptor object to vibrate), and 26 percent fewer reported the misconception that sound cannot travel through water. The research on misconceptions shows that it is difficult to replace misconceptions (Hewson and Hewson 1988); hence the need for 5E teaching cycles that revisit concepts within and across school years.

Although many articles (and some books) have been written about the preconceptions and misconceptions of students related to various science phenomena, this information is not readily available to teachers, is not presented in curriculum materials side by side with unit or lesson objectives, does not address differences among diverse students, and typically does not include instructional sequences or teaching cycles that directly identify and resolve the cognitive conflict between “school science” and students’ everyday notions of how the world works. Our 5E teaching cycles were designed to remedy that.

Identifying the preconceptions and misconceptions of students and using the 5E model for instruction can and should be part of teaching at the college level (NRC 1997). With the fellows learning the value of these approaches firsthand, they are more likely to use them as they develop their teaching style for the instruction of college students.

The research-lesson approach. The idea for the development, analysis, and documentation of a lesson series is based on the research-lesson philosophy used to teach science in elementary schools in Japan (Lewis and Tsuchida 1998). A research lesson typically requires several classroom sessions. Research lessons are classroom lessons that have some special features in terms of their development (Lewis and Tsuchida 1998). They are planned collaboratively, they focus on process (e.g., the objective might be to help students be active problem solvers or develop scientific ways of thinking), they are recorded (e.g., using audiotapes, videotapes, narrative and checklist observations, or copies of student work), they are analyzed (by the instructor and observers), and they are regarded as products to be continually refined and adapted for subsequent use by anyone. It is important to introduce the “research lesson” philosophy to the fellows and elementary teachers, because it could dramatically improve the quality of instruction in both K–12 and university education. For instance, elementary-school teachers, with the aid of high-quality professional development activities, a strong curriculum and associated supplies, and other support during the academic year, can and do become strong advocates for and promoters of science (Loucks-Horsley et al. 1998). Encouraging the creation of a school culture that includes scientific research on learning and job-embedded professional development can transform teaching (O’Brien 1999).

Implementation

Over three years, we had a total of 24 graduate teaching fellows and 9 undergraduate teaching fellows working with 38 teachers in grades 3, 4, 5, and 6, about half of the teachers in those grades in the school district. Each year we discussed the evolving state of the curriculum maps and 5E units with the current teaching fellows, participating teachers, and other school district personnel. During the summer, the teaching fellows worked with graduate students (i.e., in the Master of Arts in Teaching [MAT] program) and participating teachers to develop drafts or refinements of 5E cycles and boxes of materials for hands-on activities and demonstrations that match the cycles. Each academic year, the teaching fellows (graduate research students) and a new group of teachers completed a one-week institute that emphasized the use of the 5E teaching cycle to address student misconceptions and a walkthrough of conceptually linked 5E units aligned with the district curriculum maps and state standards.

For the teaching fellows, two additional days were devoted to classroom management, curriculum-embedded assessment, learning styles, and helping instructors develop an appropriate “cultural” perspective. Scientists and engineers tend to be very analytical and linear in their thinking and are not aware of how different their learning (and teaching) styles or multiple-intelligence profiles may be from that of students (Felder 1993, 1996). “Multiple intelligences” are the many ways that people can exhibit intelligence (Gardner 1983); an individual’s learning style is the intelligences put to work (Armstrong 1994). Nor are science majors aware that the transition for most students from the world of their daily life to that of a science classroom is truly a cross-cultural experience, and for many it is a difficult, if not a seemingly impossible, transition (Aikenhead and Jegede 1999). Science instruction needs to take these differences into account. Central to the program was developing the idea that the fellows are ambassadors of science, whose job it is to promote scientific literacy in different cultural situations (which is the responsibility of all successful citizen–scientists).

As required by NSF, the fellows spent 10 hours per week during the academic year in classrooms as science resource specialists and 5 hours per week preparing for their classroom work. The teacher–fellow teams implemented the 5E units. The units were refined on the basis of feedback from Saturday workshops with the teachers and teaching fellows, surveys filled out by the teachers and elementary students, and biweekly meetings of the teaching fellows with university faculty.
Assessment

Impact on learning was assessed with pre- and postassessment of misconceptions for each science unit, using wording obtained from published studies and summaries (AAAS 2001) and from Web sites on misconceptions (AIP 1998). For example, pre- and postassessment of misconceptions by fourth graders \((n = 37)\) about soil showed a change from misconception to accepted conception about water’s ability to break rock (via freeze and thaw) in 66 percent of the class, and a reduction of 28 percent in the misconception that “all soil is the same” (it isn’t). Considering that the 5E approach was new to the teachers, that the 5E units were still in the development stage, and that the fellows could not be there every day to reinforce concepts with teachers and students, these changes were substantial.

Another part of our assessment was the “How Did It Go?” form. For instance, for the 5E unit on plants for grade 4, all of the teachers said that they enjoyed teaching the lessons, that they planned to use them next year, that the lessons met New York State standards, and that students mastered and were quite interested in the material. These teachers also said that the teaching fellows greatly helped them implement the unit. As indicated by rubric scores from the classroom observations made by the program coordinator (a retired physics teacher), fellows improved their communication skills by 19 percent, the quality of their science instruction by 14 percent, their core-making with a teacher by 17 percent, and their use of the 5E model by 14 percent, such that by the end of a year the average score was in the top rubric level, and the program coordinator believed the fellows’ skills in these areas were equivalent to those of MAT interns.

We also used surveys for pre- and postassessment of attitudes about science held by the elementary-school students, the teachers, and the teaching fellows (box 1). An educational statistician working through Binghamton University’s Center for Learning and Teaching helped us develop these survey instruments. We obtained permission from the university’s Human Subjects Research Review Committee and from the school district to distribute the surveys.

We learned much from these surveys (tables 1, 2). For example, at the start of the institute, the elementary-school teachers were more optimistic about the quality of school science than were the fellows (table 1). Yet both the teachers and the teaching fellows indicated that in their experience of taking science courses, many topics were covered, but the ideal would have been to study a few fundamental concepts in greater depth (table 2). Both teachers and fellows also felt that their experience in science courses was heavily biased toward “knowing facts” but that the ideal would have been “understanding concepts.” That was useful information, because teachers and fellows in their own teaching practices tend to emphasize factual knowledge and broad coverage rather than covering a few key concepts well. National data support this finding and also support the contention that people tend to teach the way they were taught (Weiss et al. 2003).

Part of the power of the 5E teaching cycle, the process that is introduced to teachers and fellows in the workshops, is that it addresses how to develop key concepts incrementally and thus to provide an integrated structure for curriculum, instruction, and assessment as a seamless package. Consequently, teachers don’t have to depend on a textbook approach (often with unrelated facts; overemphasis on vocabulary; broad, superficial coverage; inaccurate or developmentally inappropriate information; and illogical sequencing of concepts). The survey results made it clear that we had to find ways to help both the teachers and teaching fellows come to terms with the inadequacies of the textbooks and with the discrepancy between their own actual practice of teaching and their ideal.

All of the teaching fellows indicated that they (a) had produced worthwhile products; (b) observed in the teachers an increased understanding of the 5E approach and increased usage of active-learning and discovery-based ways of teaching; (c) observed in their students an increase in scientific knowledge and enthusiasm for science; (d) felt the experience was

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**Box 1. Survey instruments developed for the GK–12 program at Binghamton University.**

For more information on these materials, see [http://biology.binghamton.edu/nsfk12](http://biology.binghamton.edu/nsfk12).

**Pre- and Postassessment of Students’ Misconceptions.** Short tests for each instructional unit.

**Some Questions about You.** Background about the teachers.

**Institute Evaluation.** Feedback from the teachers and teaching fellows about the summer training workshop.

**Teaching Science.** Assessment of how much science teaching occurred in the program and how the teachers feel about teaching science; given to two groups of teachers, those participating in the summer institute and those who were not.

**View of Science and Science Teaching.** Given to both teachers and university teaching fellows. The questions were derived from published surveys or lists.

**View of Science Student Questionnaire.** Given to elementary-school students. The questions were derived from published surveys or lists.

**How Did It Go?** An evaluation of the instructional units that the teachers and teaching fellows developed. The teachers participating in the project completed one form per unit.

**Rubric for Teaching Fellow Performance in Classroom.** Used by the program coordinator for in-class observations and feedback.

**Evaluation of Teaching Fellows by Faculty.** Report from faculty advisors and graduate directors on the progress of fellows and the effects on graduate programs.

**End of Fellowship.** Debriefing form given to the teaching fellows at the end of the academic year.
worthwhile; (e) planned to use the 5E teaching cycle when they teach courses of their own; (f) believed they, like their students, now had a better understanding of science; (g) had improved their communication and teamwork skills; and (h) think now that they can improve K–16 science education. The fellows were all substantially affected by the experience (box 2).

Almost every teaching fellow and participating teacher had stories about students who caused problems in class or never showed any interest in anything but now cannot wait to have the science period. Parents reported that their children were talking about science and about the scientist (i.e., the teaching fellow) in the classroom; around town, parents stopped teachers and teaching fellows to talk about this and say “thank you.” For example, one parent told a male teaching fellow how much her third-grade daughter liked science now, but then asked if it was okay for a girl to like science and if a career in science was possible for her. He assured her it was!

Discussion and conclusions

We have seen marked changes in how our partner district approaches this grant. Over the course of the last three years, we have had many meetings with the district. Coupled with the

<table>
<thead>
<tr>
<th>General statementsa</th>
<th>Agree (percentage)b</th>
<th>Teachers</th>
<th>Teaching fellows</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The general public views science literacy as important for today’s adults.</td>
<td>35</td>
<td>13</td>
<td>&lt; 0.01</td>
<td></td>
</tr>
<tr>
<td>Elementary schools are providing students with the kind of quality science education they will need in the coming century.</td>
<td>47</td>
<td>3</td>
<td>&lt; 0.00001</td>
<td></td>
</tr>
<tr>
<td>Middle schools are providing students with the kind of quality science education they will need in the coming century.</td>
<td>43</td>
<td>8</td>
<td>&lt; 0.0002</td>
<td></td>
</tr>
<tr>
<td>High schools are providing students with the kind of quality science education they will need in the coming century</td>
<td>45</td>
<td>25</td>
<td>&lt; 0.046</td>
<td></td>
</tr>
<tr>
<td>Science education reform, as exemplified by the New York State standards, will substantially strengthen science education and improve student performance.</td>
<td>52</td>
<td>30</td>
<td>&lt; 0.033</td>
<td></td>
</tr>
</tbody>
</table>

Note: Responses at beginning of the academic year are shown only for statements for which there were differences between teachers and teaching fellows.

Table 2. Survey responses of elementary-school teachers and graduate teaching fellows concerning the emphasis placed on different teaching approaches in their own education and the type of emphasis they view as ideal.

<table>
<thead>
<tr>
<th>Emphasisa</th>
<th>Experience in own education</th>
<th>View of ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teachers (percentage)</td>
<td>Teaching fellows (percentage)</td>
</tr>
<tr>
<td>Facts versus concepts (teachers versus fellows, P = 0.40; experience versus ideal, P &lt; 0.0001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphasis on knowing scientific facts and information</td>
<td>76</td>
<td>66</td>
</tr>
<tr>
<td>Emphasis on understanding scientific concepts and developing abilities of inquiry</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Balance between these</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Few fundamentals versus many topics (teachers versus fellows, P = 0.29; experience versus ideal, P &lt; 0.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphasis on studying a few fundamental science concepts</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>Emphasis on covering many science topics</td>
<td>48</td>
<td>73</td>
</tr>
<tr>
<td>Balance between these</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>Short- versus long-term investigations (teachers versus fellows, P = 0.17; experience versus ideal, P &lt; 0.0001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphasis on investigations confined to one class period</td>
<td>71</td>
<td>79</td>
</tr>
<tr>
<td>Emphasis on investigations over extended periods of time</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Balance between these</td>
<td>17</td>
<td>9</td>
</tr>
</tbody>
</table>

Note: Sample size was 58 teachers and 33 teaching fellows, except in some cases where particular questions were missed or double-answered. Only a few of the contrasts are shown here; the others showed similar patterns. Percentages may not total 100 because of rounding.

a. For each set of possible answers, respondents could either choose “strongly agree” or “agree” for one or the other of two opposing statements, or “neutral” (i.e., balance between the two statements). The contrasts were developed from an NAS (1995) publication.
enthusiasm that the teachers, students, and parents have expressed about the project, these meetings have brought a renewed focus to elementary-school science in the district. The teachers are now asking us to help them get the district to revise the science curriculum maps (which up to now have been put together by elementary-school teachers who volunteered to make the maps, regardless of their background in science, which is almost always slight), and the district is asking us to continue working with the teachers to create a groundswell of support for this revision.

The teaching fellows have had a crucial role in this process. They were in the classrooms collaborating with teachers on implementing and then refining the science units. They were instrumental in helping the teachers see the value of linear conceptual development in the curriculum maps through the year and across grades. In the process, the fellows were reflecting on what the linearity should be, which helped them be better scientists and teachers. The fellows saw that they were accomplishing much more than delivering science content to elementary-school students and helping teachers adopt hands-on science units; they were facilitating fundamental change in how the teachers thought about the development of science content and habits of mind with their students. This is especially important because the fellows tended to be unsure about their ability to relate well to elementary-school students and their teacher–partners. The fellows came out of the program realizing that they could contribute at a high and satisfying intellectual level. As they came to see the value of these partnerships, they were also becoming better scientists, and not just because they were learning to articulate complex ideas or because they were learning about the practice of teaching. They were also reflecting deeply on fundamental science and pedagogical concepts. Teaching fellows said that they now understand the logical sequencing of concepts, and
the relationships among them, in a way they never did before. We have seldom seen university teaching assistants reflect this deeply about the subject matter and how to teach it.

We did have to make refinements. Initially, we tried having the teaching fellows draft the science units from scratch, with or without the teachers’ collaboration. That didn’t work. Neither the teachers nor the fellows had the combination of expertise in science content and in curriculum development, much less the considerable time it takes, to put together a well-structured 5E teaching cycle. So we developed usable drafts of 5E teaching units that matched the curriculum maps and state standards. In addition, teachers, teaching fellows, other university faculty, and a select few MAT science graduate students provided input. Draft units were then field-tested and critiqued by the teacher–fellow teams, edited with the assistance of the MAT students, and subjected to another round of testing and revision by the next group of teacher–fellow teams. Any set of conceptually linked lessons needs continual refinement to match and track the needs of students and schools.

We made another major adjustment. We had proposed that fellows work exclusively in the classrooms focused on their disciplines (e.g., a biology fellow in grade 4 for biology units in the fall, and then in grade 5 for biology units in the spring). However, because the curriculum maps are fixed (e.g., grade 4 biology is set for certain months, not all of them in the fall) and developing rapport with students is so important, we placed fellows in the same classrooms all year. Although initially some fellows were apprehensive about serving as science generalists, all of them said that it worked out well and that it has made them better scientists. Being successful in interdisciplinary research requires a conceptual understanding of other disciplines and a familiarity with the jargon. The history of science in the last century gives credence to the value of such breadth in terms of research creativity (Hargittai 2002).

Finally, as with all grants of this type, the program has been created in the expectation that it will be sustained beyond the grant, despite financially difficult times. Across the nation, public universities are faced with increasing pressure to deliver high-quality education to large numbers of undergraduates, train graduate students to be the future leaders in scholarship and research, and partner with organizations and industry to address local, state, and national needs. At the same time, state revenues are declining, and health care and K–12 education are requiring a bigger chunk of state revenue. Consequently, higher education is receiving less. The result creates a dilemma for public universities because they are expected to make a monetary commitment to sustaining the K–12 outreach program after NSF funding ceases. Our solution has been to show school districts the value of having this partnership, which leads to their providing graduate students with stipends that are coupled with tuition scholarships from the Binghamton University graduate school. In addition, the graduate school has provided internships and tuition scholarships for students who participate in this kind of outreach beyond the requirements for a degree.

Acknowledgments

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