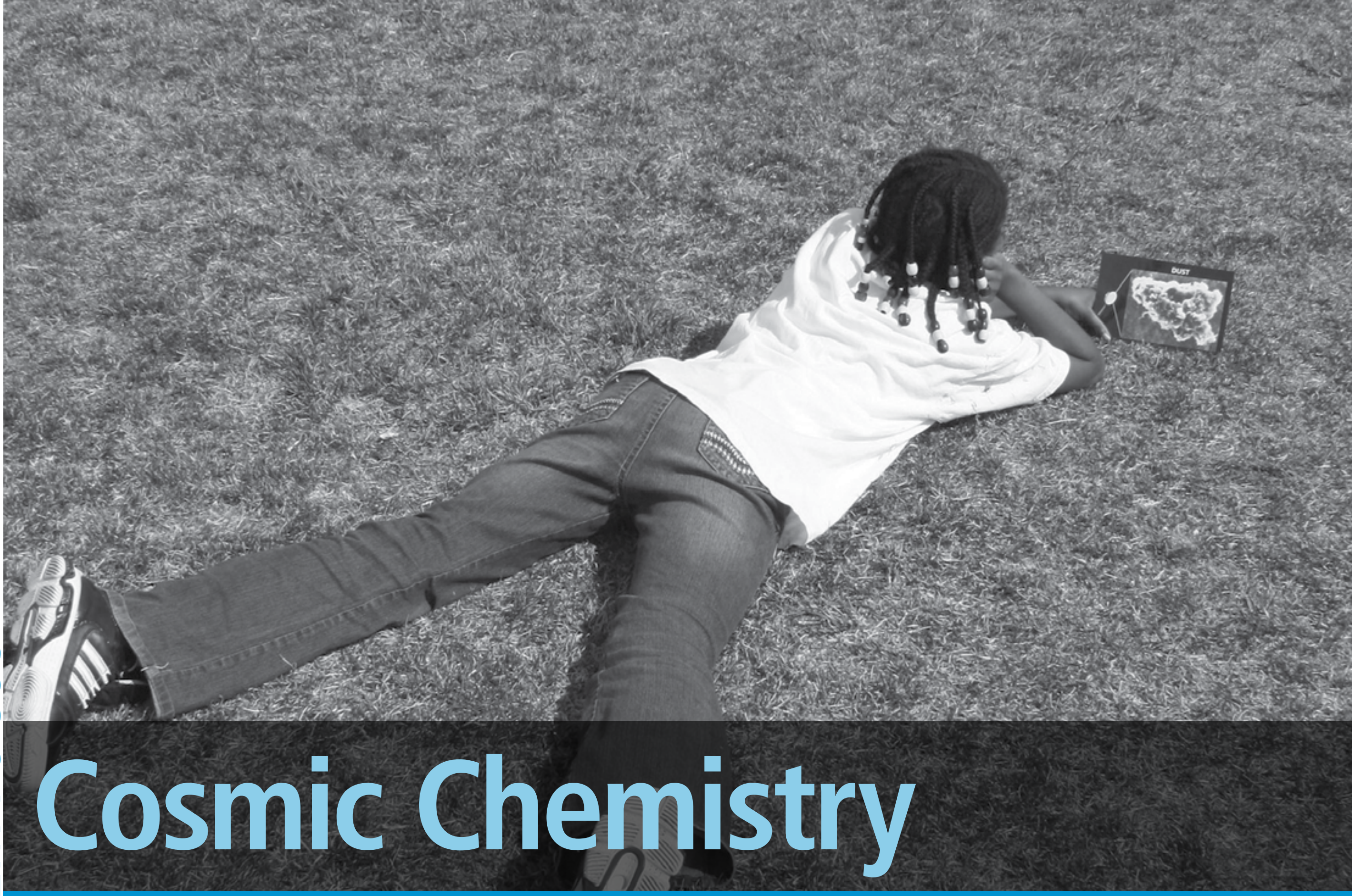

STEM FOCUS

Cosmic Chemistry

A Proactive Approach to Summer Science for High School Students

by Danette Parsley and John Ristvey

Though school is out for the summer, ninth- and tenth-grade students at Union Intermediate High School are burning off energy playing a game of tag on the soccer field. But that's not all they're doing. They're also synthesizing and applying key chemistry concepts they've just learned related to the conditions of the early solar system. They are acting out concepts including the fundamentals of matter—atoms, ions, and isotopes—while deepening their understanding of how the solar nebula transformed into our present solar system about 4.6 billion years ago.

These students are engaged in Cosmic Chemistry—a two-week summer learning program focused on chemistry with an astronomical twist. Why do districts, including Union Public Schools in Tulsa, Oklahoma, choose to implement summer programs that, like Cosmic Chemistry, address science concepts? Some districts use summertime to help reinforce or remediate learning from the previous year. Others, like Union, hope to *accelerate* future learning by providing young people with engaging, high-quality learning that builds a foundation of essential knowledge and skills for next year's science content. Cosmic Chemistry engages ninth and tenth graders to prepare them to take chemistry in school the following year. This proactive approach to summer learning provides rigorous, relevant science experiences to help the students who need it most *before* they fall behind. Cosmic Chemistry was developed by educators at McREL

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International and Education Northwest. Our process of designing, implementing, and evaluating Cosmic Chemistry offers lessons that may be useful to designers of other academically oriented out-of-school time (OST) programs.

Research-Based Recommendations on Designing OST Programs

Over the last decade, the number of schools, districts, and community-based organizations implementing academically oriented OST programs like Cosmic Chemistry has increased dramatically (Stonehill et al., 2009). To respond to these programs' need for research-based guidance, the Institute of Education Sciences (IES) convened an expert panel to review existing research and generate recommendations for designing, delivering, and evaluating high-quality OST programs (Beckett et al., 2009). The IES panel, comprising OST program and research experts, reviewed the best available research, ranging from rigorous program evaluations to expert analyses of OST strategies and practices. To identify replicable practices, the panel paid particular attention to experimentally and quasi-experimentally designed studies.

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The review began with a comprehensive search of studies conducted in the previous two decades. Of just over 1,000 studies found, 130 met the criteria for further review. Of these, 22 studies of 18 different OST programs met the What Works Clearinghouse evidence standards as randomized controlled trials, regression discontinuity studies, or quasi-experimental studies with no design flaws. These studies were therefore used as the foundation for five recommendations on designing OST programs to improve academic performance:

- Align the out-of-school time program academically with the school day
- Maximize student participation and attendance
- Adapt instruction to individual and small-group needs
- Provide engaging learning experiences
- Assess program performance and use the results to improve the quality of the program (Beckett et al., 2009, p. 11)

Acknowledging that the OST research is not yet robust enough to provide definitive best practices, the panel recommended more rigorous research. Even so, the recommendations reflect the current theory and practice of designing and implementing academically oriented OST programs.

Program Description

Using the IES recommendations, we led the project team that designed a two-week summer learning experience based on NASA educational materials originally developed for use during the school day. We intentionally sequenced the learning to promote a coherent content storyline that allows students to engage with the content many times and in different ways.

Cosmic Chemistry was designed for "middle-of-the-road" students. Sometimes referred to as "the forgotten middle," these students are easily identified by their academic, behavioral, and attendance records. Their classroom grades are typically Cs, with occasionally a few Bs and Ds; they generally score solidly in the middle on state assessment tests. They rarely are singled out for disruptive or even non-cooperative behavior; generally they listen in class but do not speak up without prompting. Most attend school consistently. They are neither failing nor excelling. Since they don't have expressed or obvious problems, their parents and teachers seem content to pass them along (Swanson, 2005). This silent majority constitutes a large part of the middle two quartiles of U.S. students. By default, these millions of "average" students are consigned to low expectations. According to Bridgeland, DiIulio, and Morison (2006), they could be at risk of dropping out. When these researchers interviewed recent high school dropouts, they found that a majority reported making C grades or better at the time they quit school. These students in the middle of the academic spectrum reported that they felt ignored, invisible, and forgotten. The researchers speculate that perhaps these students would have remained in school and graduated had someone taken notice (Bridgeland et al., 2006).

Before launching Cosmic Chemistry, the project team provided professional development for facilitators and developed instruments to evaluate the program using multiple data sources. During the summers of 2010 and 2011, science teachers at Union Intermediate High School delivered Cosmic Chemistry to eager students who were hoping to get a boost for chemistry class the following year.

A week before the start of the two-week summer program, students and parents attended a kickoff event at the Tulsa Air and Space Museum. Teachers met with Cosmic Chemistry students in an informal environment, and students and their families were introduced to the context of the program: NASA's Genesis mission. The Genesis spacecraft launched in 2001 on a mission to collect pieces of the sun in order to learn more about the conditions of the early solar system. When the spacecraft returned in 2004, the parafoil on the sample return capsule did not deploy. As a result, the capsule crashed into the desert in Utah with its precious cargo, amounting to just a few grains of salt's worth of solar wind (charged particles from the sun). During a keynote address at the kickoff event, parents and students learned that, even though the mission had suffered a huge setback, scientists were able to meet all of the mission objectives through hard work and perseverance. The Genesis mission is a real-life example of science as a human endeavor. During the kickoff event, students were encouraged to strive for excellence throughout the summer and the upcoming school year.

During the first week of Cosmic Chemistry, students learned more about the Genesis mission from engineers and scientists who either were directly involved in the mission or came from the local community. Hands-on and virtual activities wove the story of Genesis together with chemistry fundamentals. For example, students developed models of the structure of the atom, with its protons, neutrons, and electrons. One popular activity at the conclusion of the first week introduced students to the standard solar model by modeling the fusion reaction in the core of the sun. In "Proton Smasher," blindfolded students threw Velcro balls representing protons at a Velcro target ball, trying to make their balls stick to the target. (See Figure 1. Videos of this and similar activities are available on YouTube; search on "Cosmic Chemistry.") In the core of the sun, the average solar proton takes 14,000 million years to find a "hot partner" with which to fuse. Protons in the sun's core not only travel for long periods without colliding, but may also collide many times without fusing. In the modeling activity, students noticed that the "protons" had to collide at the right speed, at the right angle, and with enough energy for "fusion" to occur. Later, students learned about the different types of solar wind, using actual data taken from the Genesis spacecraft. Each day in the Cosmic Chemistry program, students had ample time in small groups to explore key concepts through structured sense-making activities. Student groups spent time talking, writing, and drawing as they prepared a museum exhibit-style presentation on a topic of their choice, which they delivered to their peers, their parents, and members of the community during the last day of the program.

Figure 1. Proton Smasher activity

Most of what Union students said in interviews and surveys that they liked best about Cosmic Chemistry could be offered in any science program: having the flexibility to choose projects that were personally interesting, developing both the skills and the confidence to present in front of people, doing science instead of just reading about it, learning things that are relevant to the classes they will be taking, and believing that they could understand an authentic science endeavor.

Designing and Delivering High-Quality Summer Science Programming

Cosmic Chemistry is grounded in research-based OST best practices that are associated with increased student achievement and are conducive to implementing dynamic programs (Beckett et al., 2009; Fairchild, McLaughlin, & Brady, 2006). Research suggests that summer is a particularly important time to engage students in high-quality learning experiences (Beckett, 2008; Bell & Carrillo, 2007; Fairchild et al., 2006; McCombs et al., 2011; McLaughlin & Pitcock, 2009; Terzian, Moore, & Hamilton, 2009). High-quality summer programming that follows the IES practice guide is characterized by alignment with academic content standards and the school year curriculum, maximum student participation and attendance, tailored and engaging learning experiences, and evaluation of outcomes (Beckett et al., 2009).

Aligning with the School Day

According to IES panel recommendation 1, designing and delivering high-quality OST programs requires aligning the program academically with the school day—without repeating content. To ensure alignment with typical high school chemistry classes, Cosmic Chemistry developers centered the curriculum on the National Science Education Standards (National Research Council, 1996), which are foundational for student success in chemistry. The standards include both core concepts—the structure of atoms, the structure and properties of matter, the interactions of energy and matter—and core skills necessary for scientific inquiry, such as the ability to use technology and mathematics to investigate and communicate.

Even when the OST curriculum is standards-based, as is the case with Cosmic Chemistry, program coordinators and school and district staff still play a key role in aligning it to the school day. The program coordinator should work with a school contact person, such as the district science coordinator or the science department chair, to ensure program alignment and make any necessary adjustments. The program coordinator must develop strong relationships and maintain ongoing communication with the school-day staff. Effective communication and collaboration between the program coordinator and school contact can facilitate important tasks, such as:

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- Collecting student data
- Identifying and intentionally recruiting students who would benefit from program participation
- Identifying and recruiting staff who can serve as summer program facilitators, assist with professional development, or both
- Identifying community-based and business partners to support the program, including guest speakers

Maximizing Participation

IES recommendation 2 is about maximizing student participation and attendance. To help maximize student attendance and participation in summer STEM programs, schools should promote the programs widely using a variety of communication mechanisms. They should identify multiple strategies for recruiting students who might benefit from an academic jumpstart. Program planners should take into account the needs and preferences of students and parents, including transportation, location, and hours of operation. Districts might also consider extending the program to offer additional enrichment or recreational activities, depending on family needs and preferences.

When preparing to run Cosmic Chemistry, the Union Intermediate High School program coordinator identified incentives for and potential barriers to participation on the part of the middle-of-the-road students for whom the program was designed. Incentives included an optional extension to allow students to earn half a credit on completion and presentation of a capstone project. The program was scheduled for half days during the first few weeks of summer to allow students both to participate in the program and to work a summer job. Based on expressed needs of participating students and their parents, Union arranged to provide breakfast and lunch each day as well as transportation to and from the program for any student who needed it. While the program was running, the program coordinator and facilitators at Union carefully tracked attendance and worked with individual families to solve problems when students had trouble attending.

Tailored and Engaging Learning Experiences

Recommendations 3 and 4 from the IES panel focus on instructional delivery. To meet students' specific learning needs, programs should provide targeted, intentionally designed learning experiences that are engaging and active and that maximize the flexibility OST environments offer.

The Cosmic Chemistry curriculum is highly interactive. Students frequently work in small groups to conduct experiments, interact with scientists and engineers, use virtual and hands-on simulations, make sense of content, and prepare for the museum exhibit presentation. The curriculum fosters high expectations, focusing on ways that facilitators can personally communicate and demonstrate these high expectations throughout the program. Cosmic Chemistry also incorporates several activities to encourage families to set high expectations as well: the family kickoff event, which promotes shared ownership of program goals and expectations; daily student sense-making and wrap-up activities that include family communication; and involvement of family members in final project presentations.

In Cosmic Chemistry, students practice the collaboration and presentation skills that they will ultimately need in daily life but that are often neglected in modern chemistry classrooms. They interact with practicing scientists in ways that connect to real, cutting-edge science currently under study and that promote thinking about future careers. The program culminates with students presenting their new knowledge to an audience made up of their peers, community members, and families. This level of interactivity and personal empowerment, combined with standards-based content and research-based instructional strategies, helps increase the engagement, confidence, and voice of students who fall into the otherwise forgotten majority of middle-performing students.

OST programs often offer larger blocks of time for learning than schools can. This extra time can be used to vary instructional strategies and to provide hands-on learning opportunities to engage students and deepen their understanding and retention. The selection of strategies should be based on timely information about students' knowledge and skills. Cosmic Chemistry uses specific OST science practices recommended by the National Partnership for Quality Afterschool Learning (n.d.).

Investigating science through inquiry is the process of exploring scientific questions and proposing explanations by making observations, conducting investigations, and using data. In Cosmic Chemistry, students conduct a guided inquiry to investigate the question, "What is the sun made of?" Students analyze a model of solar wind retrieved by the Genesis spacecraft to understand how the elemental composition of the sun is measured.

Exploring science through projects and problems involves real-world learning experiences that interest and engage young people, make science relevant, and encourage them to solve problems. Cosmic Chemistry students work in small groups to learn about real-world chemistry applications, such as career opportunities or cleanroom technology. They work on their selected project throughout the two-week program; on the final day of the program, they present what they learned to program facilitators, peers, and family members.

Integrating science across the curriculum means that science projects incorporate content or skills from other subject areas such as math, reading, writing, social studies, and the arts. In Cosmic Chemistry, students practice essential math skills such as graphing, calculating ratios and proportions, and working with logarithms. They hone writing and speaking skills as they engage in sense-making activities, build models, and prepare presentations. Students learn a historical perspective of science as they encounter early ways in which scientists organized elements. They see how technology was used to design, build, and implement a real NASA mission by interacting with scientists and engineers and by experiencing a virtual field trip.

Engaging families and communities in science means involving parents and community partners in fostering positive attitudes, enhancing science literacy, and making science relevant. Cosmic Chemistry engages families in science through the kickoff event, daily opportunities for students to share what they've learned through their social networks, and participation in the museum exhibit on the final day of the program. The program engages community members in science by having students interact with practicing scientists in ways that promote thinking about future careers.

Evaluating and Improving the Program

Recommendation 5 from the IES panel focuses on program evaluation. Program leaders should use formative and summative evaluation to assess program performance. They can improve the program by collecting, analyzing, and acting on data on program implementation, stakeholder satisfaction, and student outcomes.

To ensure that evaluation activities are feasible and relevant, evaluation instruments to monitor implementation and tools to measure student outcomes are built right into the Cosmic Chemistry program coordinator guide. Some instruments were developed specifically for Cosmic Chemistry, while others were adapted from existing tools. For example, the classroom observation protocol used 14 items from *Inside the Classroom Observation and Analytic Protocol* (Horizon Research, 2000), while individual facilitator logs were specific not only to Cosmic Chemistry but even to each day's lessons.

The observation protocol and facilitator logs help with assessing how the program is being implemented. Program coordinators or district personnel can use observation data to evaluate program activities, while facilitators and program coordinators can use the daily logs to reflect on how they teach and manage the program.

In the 2010–2011 pilot, observations by project evaluators provided a measure of implementation fidelity. The daily logs provided insight on facilitators' perceptions of how well the program promoted chemistry knowledge, motivation, and high expectations. We found the observation and log data to be especially helpful in determining adjustments that needed to be made to student learning experiences and to facilitator professional development. For example, observations during the first pilot test led to several revisions to both the curriculum and the professional development for instructors. We adjusted the daily pacing, reordered and reduced some of the content, and added many structured student-led sense-making opportunities. We also incorporated into the facilitator materials a more robust set of strategies for communicating and demonstrating high expectations.

To measure student outcomes, the team developed or adapted instruments for specific purposes:

- A chemistry foundations assessment was developed to align with the National Science Education Standards addressed in Cosmic Chemistry.
- A high expectations questionnaire based on the IES practice guide explores students' perceptions of whether facilitators provide challenging work, encourage goal setting and doing one's best, and expect student participation.
- A questionnaire on student motivation and perceived competence includes three scales from two established instruments in the field: the Attitude Toward Science in School assessment (Germann, 1988) and the Perceived Competence Scale (Williams, Freedman, & Deci, 1998).

During the second year of implementation, we found that students improved in all three areas, most notably in the area of background knowledge. Data from the chemistry knowledge assessment were aggregated and reviewed by instructors during a professional development session. Based on the data, facilitators discussed which concepts to emphasize and any implications for planned activities. Students scored an average of 34.8 percent correct on the pre-test and an average of 59.5 percent correct on the post-test. In response to the interview question, "Was Cosmic Chemistry what you expected?" one student said:

> I felt like this was going to be a class in which we studied from textbooks, but I like this instead of what I expected. It's a lot better to remember, and every bit of the activities and projects were very interesting.

On the high expectations questionnaire, which students completed at the end of the two-week Cosmic Chemistry program, students reported that the teachers held high expectations of them. The confidence and motivation assessment showed that students' motivation was higher on the post-test than on the pre-test, though the difference was not statistically significant. Another indicator of motivation and confidence is the fact that 82 percent of students in the second year of the program went on to take pre-AP chemistry. In open-ended feedback, one student expressed enthusiasm in response to the question about whether students would recommend Cosmic Chemistry to others:

> Yes, yes, yes. A million times yes. Cosmic Chemistry was so fun and hands on and just all around exciting that I absolutely loved it, and I'm pretty sure anyone else will too.

Cosmic Chemistry evaluation instruments were developed to align with program goals. They not only give program facilitators and coordinators the information they need to make mid-course adjustments as necessary but also provide summative data to assess how the program affects student outcomes. The facilitator guide provides guidance for administering the instruments, summarizing the data, and discussing results. Involving program staff in using evaluation data helps them tailor instruction and improve the experience for students each time the program is delivered.

Limitations

Because Cosmic Chemistry was primarily a development project, our study has several limitations. First, we were limited to one district for the pilot and field testing. Limiting the scope in this way allowed us to work closely with the program coordinator and summer facilitators and to focus on aligning the program with just one in-school science curriculum. In subsequent studies, we hope to test the efficacy of Cosmic Chemistry in a wider set of districts and schools. Second, only 27 students completed the field test program and provided data, mostly because middle-of-the-road high school students have other time commitments during the summer such as sports camps, jobs, and family vacations. Finally, we did not compare our sample of students with a control group who did not complete the program. Nor did we collect data, other than anecdotal information, from Cosmic Chemistry students during the school year, when they were enrolled in chemistry classes. Future research will focus on more comprehensive study of these conditions.

Mission Accomplished

A primary goal of Cosmic Chemistry is to prepare students to enroll and succeed in high school chemistry by building their foundational chemistry knowledge and increasing their motivation to pursue higher-level science courses. We hypothesized that realizing this goal would require setting and demonstrating high expectations in an engaging OST experience based on real-world experiences in space science. Our findings from the classroom observations and facilitator logs revealed that Cosmic Chemistry can accomplish this goal and that facilitators can implement it with fidelity on a daily basis. Students' achievement in basic chemistry concepts increased significantly from pre-test to post-test, with large effect sizes. Following Cosmic Chemistry, almost all of the students chose to go into chemistry or pre-AP chemistry classes.

Based on these findings and our experience, we are confident that programs like Cosmic Chemistry can have a positive effect on student learning and prepare students for future opportunities to study science. Such programs are designed and implemented using the recommendations from IES; they intentionally integrate best instructional practices appropriate for the content area. OST program designers might consider using some or all of the specific practices that we used in the design and delivery of Cosmic Chemistry, as summarized in Table 1.

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Table 1. IES Recommendations and Corresponding Program Practices

IES RECOMMENDATION	COSMIC CHEMISTRY PRACTICES
1. Align the OST program academically with the school day.	Identify a small number of core concepts in the content standards that are aligned with school curriculum.
2. Maximize student participation and attendance.	Create incentives for participation. Remove or minimize barriers to participation.
3. Adapt instruction to individual and small-group needs. 4. Provide engaging learning experiences.	Provide a real-world context for learning. Use various grouping strategies, including small groups. Demonstrate high expectations for students. Use a variety of content-specific instructional practices, such as: • Investigating science through inquiry • Exploring science through projects and problems • Integrating science across the curriculum • Engaging families and communities in science
5. Assess program performance and use the results to improve the quality of the program.	Use instruments specifically tailored to program goals and strategies. Collect, analyze, and use program implementation data to monitor and make adjustments to program design and delivery. Collect, analyze, and use stakeholder satisfaction and student outcome data to assess program impact.

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