Using Student Posters to Investigate the Impact of Inquiry-Based STEM Learning on Rural K-12 Students

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Abstract

This study examines student posters produced as part of the Colorado SCience and ENgineering Inquiry Collaborative (SCENIC) program, which engages rural K-12 students in inquiry-based STEM projects. SCENIC leverages low-cost, portable sensor pods that enable students to measure environmental parameters in both air and soil. Through partnerships with the University of Colorado Boulder, student mentors work directly with rural classrooms to guide groups as they formulate research questions, design experiments, collect data, and ultimately present their findings at school-wide symposia. The program features two initiatives: the established Air Quality Inquiry (AQIQ) program, which deploys pods that measure pollutants in the air, and the newer Soil Quality Inquiry (SQIQ) program, which deploys pods that measure soil quality. In our study, 185 posters from both AQIQ and SQIQ initiatives were analyzed using a coding rubric to assess the balance between scientific inquiry and engineering design and create recommendations for SCENIC. Results indicate that students predominantly engaged in science-based, hypothesis-driven investigations rather than engineering elements such as problem identification and iterative solution development. Analysis revealed that increased teacher experience with SCENIC correlated with a stronger emphasis on engineering content and improved clarity in data presentation, whereas larger class sizes were associated with a diminished engineering focus. Importantly, no statistically significant difference was observed between the two inquiry platforms in terms of their ability to support the integration of engineering concepts. We conclude with recommendations for curricular scaffolding and ongoing teacher professional development, aiming to increase rural engineering and engagement in SCENIC and, more broadly, in rural-based inquiry education.

Introduction

In the United States, rural settings are an important and frequently under-resourced and under-researched cultural context for education [1], despite the fact that approximately half of school districts, a third of schools, and a fifth of students in the United States are located in rural areas [2][3]. Rural students are underrepresented among college attendees and STEM majors [4][5], with a larger proportion of students unprepared for engineering identity formation and with lower retention throughout engineering pathways [6][7].

SCENIC Colorado

To bridge this gap in rural engineering education, the Colorado SCience and ENgineering Inquiry Collaboration (SCENIC Colorado) has been conducting programming that connects University of Colorado Boulder student mentors with rural K-12 schools to facilitate student-led, inquiry-based projects. The Hannigan Air Quality (HAQ) Lab at the University of Colorado Boulder has developed and deployed low-cost, portable Air Quality (AQ) pods to measure a variety of pollutants, including carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), and particulate matter (PM). SCENIC's curriculum leverages this monitoring equipment from research settings that are not typically available in rural K-12 schools as a vehicle for students to study environmental topics. Since 2013, SCENIC has been conducting these student projects with the AQ pods, known as the Air Quality Inquiry (AQ-IQ) project.

In 2021, HAQ Lab launched a soil quality version of the pods, initiating the Soil Quality Inquiry (SQ-IQ) arm of SCENIC, which operates alongside AQ-IQ. These pods measure soil CO_2, soil moisture, temperature, and sunlight.

CU student mentors take year-long courses culminating in trips to schools, along with pods. K-12 students are put into groups, and receive a pod to conduct an experiment of their own choosing. Groups come up with a research question, formulate a hypothesis, gather and analyze data, and draw conclusions. The culmination of their efforts are student posters, which are showcased at a school-wide symposium.

As shown in Figure 1, by providing K-12 rural students with resources, mentorship, and experience aligned with STEM education, SCENIC aims to develop engineering & science identity and engagement among underserved rural students. The program works with hundreds of students annually across a dozen Colorado schools.

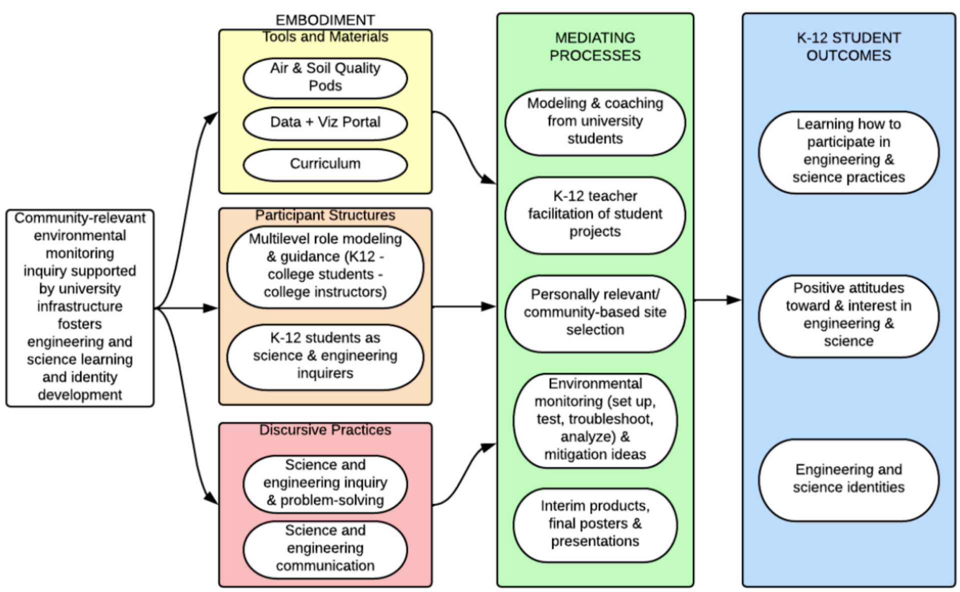

Figure 1. SCENIC Conjecture Map (adapted from [9])

Problem Statement and Research Questions

The goal of the grant this paper works under is to refine and investigate SCENIC's infrastructure to support the development of pre-college students' engineering identity, thinking, and pathways. In this paper, using student posters, we hope to explore the following:

- **RQ1:** How do the student posters from SCENIC reflect the balance between science and engineering emphasis? Did this differ between the AQ and SQ curricula or other characteristics of a school's implementation?
- **RQ2:** Does student data quality evident in the poster vary between the AQIQ and SQIQ or among different classes/schools?
- **RQ3:** What themes (e.g., fire mitigation, agriculture) emerge most prominently, and how might that relate to the cultural context of rural students?

Literature Review

This section synthesizes research on inquiry-based learning, rural STEM education, artifact-based assessment (via student posters), and coding rubrics/matrices in educational evaluation. Together, these areas frame our investigation of K-12 engineering inquiry-based learning.

Inquiry-Based STEM Learning

Inquiry-based learning places students at the center of the learning process by engaging them in asking questions, planning investigations, and constructing explanations from evidence. Numerous studies have demonstrated that such pedagogies enhance students' critical thinking, problem-solving, and conceptual understanding [10][11]. Moreover, inquiry-based approaches are a cornerstone of the Next Generation Science Standards (NGSS), which emphasize not only content knowledge but also the practices of science and engineering [12]. Research comparing inquiry-based methods with more traditional, teacher-directed approaches indicates that when students tackle authentic, real-world problems, they are more likely to develop the skills needed for future STEM careers [13].

Rural STEM Education

Rural schools often confront challenges such as limited resources, geographical isolation, and a shortage of qualified STEM educators [14]. Despite these obstacles, rural contexts can offer unique opportunities for place-based engineering education: rural students are likely to bring a wealth of knowledge that aligns well with engineering, including hands-on skills and practical problem-solving. A growing community is investigating how STEM connections to local environmental and community contexts can enable educators to foster more relevant and engaging learning experiences [15][16]. Further, although engineering education is increasingly being integrated into K-12 education, it is particularly rare in rural settings. Thus, engineering content should be integrated into science or math courses rather than planning on stand-alone courses focused on engineering.

Student Artifacts in STEM Assessment

Within the secondary curriculum of the SCENIC program, the learning culminates with a poster symposium. Students are provided a template and examples from university students who recently conducted similar inquiry projects, and then create their own posters. Artifacts such as student-created posters can serve as rich sources of evidence for evaluating inquiry-based projects. These artifacts capture not only the data collection and analysis aspects of scientific inquiry but also the iterative design and problem-solving processes inherent in engineering practices [17]. Analyzing posters allows researchers to assess how students integrate theoretical explanations with practical applications. Such assessments inform curriculum development by highlighting areas where students may need additional scaffolding.

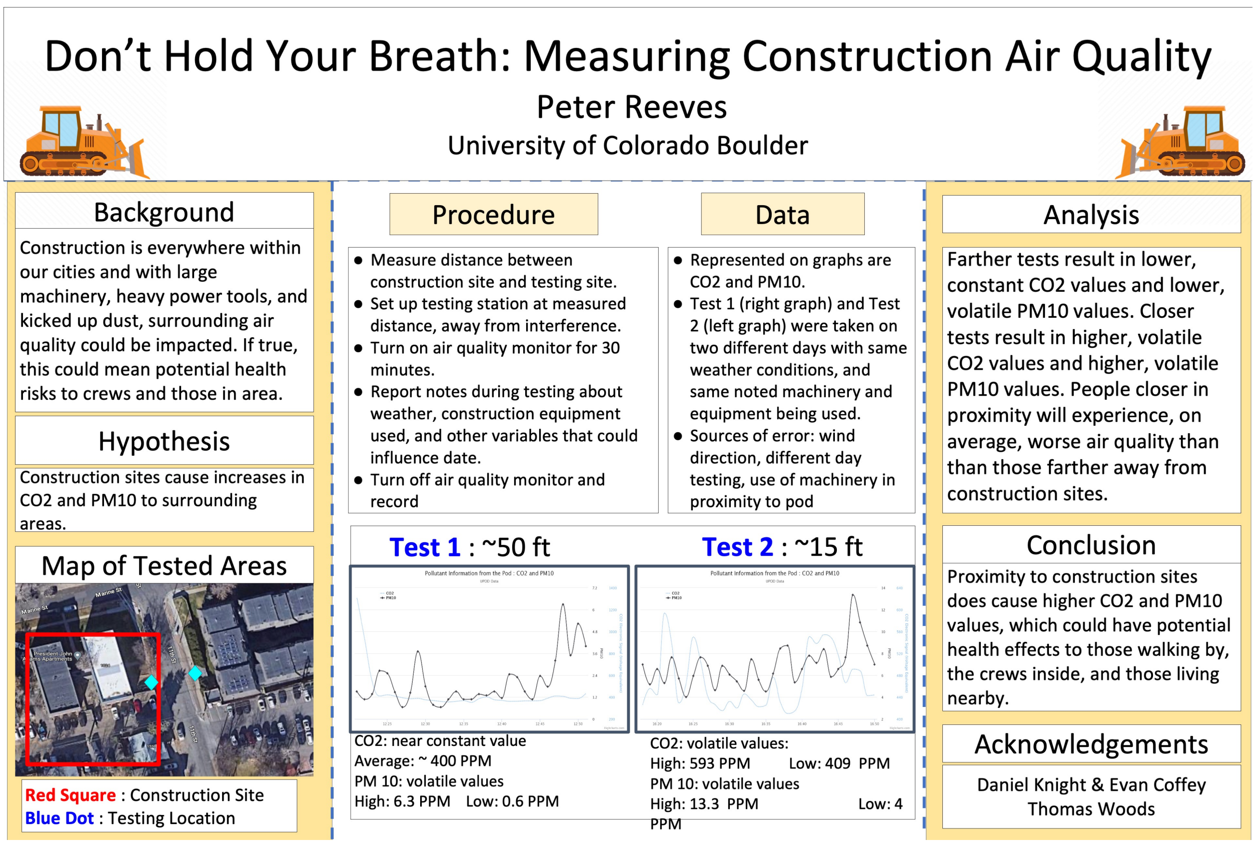

Figure 2. Example of Mentor Poster, which is representative of the template provided to the K-12 students

Coding Rubrics and Matrices in Educational Evaluation

Coding rubrics and matrices provide systematic frameworks for analyzing student work, enabling structured and consistent evaluation of both qualitative and quantitative dimensions of student projects. Coding rubrics have been used to assess the integration of scientific inquiry and engineering design by clearly outlining performance levels for various dimensions such as problem definition, data analysis, and application of theory [18][19]. Matrices that combine multiple dimensions have emerged as effective tools to capture the interplay between various learning outcomes [20], helping educators and researchers identify strengths and areas for improvement to better support student learning in STEM education [21].

Synthesis

While the literature supports both inquiry-based learning and the use of rubric-based evaluation methods, there are few investigations that have integrated these approaches to analyze student artifacts in rural STEM settings. Although research has documented the benefits of inquiry-based learning and highlighted the unique potential of rural education environments, there is a notable gap in systematic analyses that combine artifact analysis with coding rubric matrices. This study addresses that gap by applying a coding matrix approach to student posters from the SCENIC Colorado program, aiming to investigate the impact of inquiry-based rural education on the posters. The insights gained are expected to inform improvements in the SCENIC program and in rural STEM education.

Methodology

This study employs a mixed-methods approach that integrates qualitative artifact analysis with quantitative statistical evaluation. In what follows, we describe the research design, sample and data collection procedures, coding and evaluation framework, and data analysis techniques.

Research Design

The overall design is a comparative analysis of student posters, in which qualitative observations are translated into quantitative data through a coding/rubric matrix approach. This design enabled us to examine differences across groups—specifically between posters originating from the Air Quality Inquiry (AQIQ) and Soil Quality Inquiry (SQIQ) arms of the program, as well as across classrooms. The mixed-methods nature of the study bridges the gap between qualitative content analysis and statistical testing, thereby providing a nuanced view of how inquiry-based STEM learning manifests in these artifacts.

Sample and Data Collection

A total of 185 posters were selected for analysis. The posters were chosen from recent academic seasons (2021-22 and 2022-23) and represent work from both the AQIQ and SQIQ programs.

Table 1. Number of Posters by School, Academic Year, and Poster Type

School	Year	Type	Course	Students	Posters
A_1	2021–22	AQIQ	AP Environmental Science	57	22
B	2021–22	AQIQ	General Science	110	39
C	2021–22	AQIQ	Global Science	18	6
D_1	2021–22	AQIQ	Chemisty	65	20
D_2	2021–22	AQIQ	Chemistry	37	12
E	2021–22	AQIQ	AP Environmental Science	81	35
A_2	2022–23	SQIQ	AP Environmental Science	46	18
D_3	2021–22	SQIQ	River Dynamics	43	15
D_4	2022–23	SQIQ	River Dynamics	46	18

Note: Schools A & D had multiple different classes, which are listed separately in the table.

Coding and Evaluation Framework

To systematically evaluate the posters, we created a coding guidebook that transforms them into a set of quantifiable data. The coding framework consists of three sets of criteria: 1) *science/ engineering emphasis*, 2) *clarity of data presentation*, and 3) *application to certain fields*. Each of these schemes consists of clarifying buckets to determine how posters are coded. Each variable is independent (e.g., a poster can be rated as applicable in both agriculture and conservation). Regarding reliability, an independent rater coded 20% of all student posters. Inter-rater agreement for likert variables was 77%, and above 90% for binary variables.

Table 2. Scale definitions for each variable in coding rubric

Variable	0	1	2	3
Science vs Engineering	Purely Science	Leans Science	Balanced	Leans Engineering
Data Clarity	Unclear	Somewhat Clear	Clear	
Agriculture Application	No	Yes		
Conservation Application	No	Yes		
Wildfire Application	No	Yes		
Healthcare Application	No	Yes		

Results

RQ1. Science vs. Engineering

Table 3 presents the number of student posters that were coded at each level of the rubric for the extent that they represented science or engineering concepts. As is shown, most of the posters (57%) were rated at Level 1, representing 'leans science' in the information presented in the poster. Only 10% of the posters were balanced (Level 2), and none had more engineering than science (Level 3). A higher percentage of the SQIQ posters were rated at Level 0 (fully science) than the AQIQ posters; 45% versus 29%, respectively. However, the differences in the ratings of AQIQ and SQIQ were not statistically significant (Mann-Whitney U test p=0.20).

Table 3. Number of Student Posters Rated at each level of the Science vs. Engineering rubric

School	Year	Poster Type	Number of Posters at Rating Level				Avg Score
			0	1	2	3	
A_1	2021–22	AQIQ	1	17	4	0	1.14
B	2021–22	AQIQ	17	21	1	0	0.59
C	2021–22	AQIQ	1	3	2	0	1.17
D_1	2021–22	AQIQ	3	12	5	0	1.10
D_2	2021–22	AQIQ	5	7	0	0	0.58
E	2021–22	AQIQ	12	22	1	0	0.69
A_2	2022–23	SQIQ	7	8	3	0	0.78
D_3	2021–22	SQIQ	12	2	1	0	0.27
D_4	2022–23	SQIQ	4	13	1	0	0.83
					AQIQ Average:		0.81
					SQIQ Average:		0.65

Table 4 presents an ordinal regression for parameters that predict science vs. engineering outcomes in student posters. The cutpoint represents the threshold values on the latent scale that separate different ordinal categories in the regression model. The significance of these cutpoints ($p = 0.043$ and $p < 0.001$) indicates that the distinctions between the ordinal categories are meaningful, suggesting that the model effectively differentiates between engineering- and science-oriented classifications. This further validates our rubric.

Perhaps most interesting is the lack of significance found between AQIQ and SQIQ in predicting science vs. engineering in student posters, suggesting that the pod platform students used had no effect on science vs. engineering outcomes.

However, significant results did arise based on the number of students in a class, which negatively correlated with engineering in posters, and years that an instructor has been working with SCENIC, which strongly correlated towards engineering.

Not listed in this table are the different schools as cofactors. Because classrooms were codependent with other variables, any significance to their results could be attributed to the interactions between school-dependent factors and other variables like AQ vs. SQ, rather than being solely due to one independent variable.

Table 4. Science vs. Engineering Ordinal Regression

Parameter Type	Parameter	Coefficient	Std. Error	Sig.
Cutpoint	Engineering vs science = 0	2.841	1.402	.043
	Engineering vs science = 1[a]	6.251	1.490	<.001
Covariable	Students on team	0.230	0.217	0.289
	Number of students in class	-0.197	0.071	.006
	Years of SCENIC teacher instruction	3.063	1.014	.003
Cofactor	AQIQ	0.482	0.732	.509
	SQIQ[b]	0	.	.

[a] No student posters coded as a 3 (leans engineering), which leaves only two cutpoints.

[b] This parameter is set to zero because it is redundant.

RQ2. Data Clarity

The number of student posters coded at each level of data clarity is shown in Table 5. Given the range of average scores among AQIQ and SQIQ, no significant differences are obvious between the two curricula. Table 6 presents an ordinal regression for parameters that predict data clarity outcomes in student posters. Different from Table 4, the significance of these cutpoints ($p = .190$ and $p = 0.004$) indicates that the distinctions between data presentation being unclear and somewhat clear is not significant, suggesting that the regression struggled to delineate between a 0 and 1 score. Looking at our posters, most were scored as either a 1 or 2 (somewhat clear or clear data presentation), which suggests a lack of posters coded as a 0 most likely contributed. Nonetheless, the delineation between a 1 and 2 remains significant, which sets up our parameters for interpretation.

Table 5. Number of Student Posters Rated at each level of the Data Clarity rubric

School	Year	Poster Type	Number of Posters at Rating Level			Avg Score
			0	1	2	
A_1	2021–22	AQIQ	1	10	11	1.45
B	2021–22	AQIQ	4	13	22	1.46
C	2021–22	AQIQ	1	1	4	1.50
D_1	2021–22	AQIQ	3	9	8	1.25
D_2	2021–22	AQIQ	2	9	1	0.92
E	2021–22	AQIQ	0	7	28	1.80
A_2	2022–23	SQIQ	4	8	6	1.11
D_3	2021–22	SQIQ	2	7	6	1.27
D_4	2022–23	SQIQ	1	4	13	1.67
					AQIQ Average:	1.47
					SQIQ Average:	1.35

Only years of SCENIC teacher instruction correlated positively with data clarity; all other variable correlations were not significant. However, data clarity scores between classrooms varied considerably, with different classrooms presenting both as positive and negative predictors of data clarity.

Table 6. Data Clarity Ordinal Regression

Parameter Type	Parameter	Coefficient	Std. Error	Sig.
Cutpoint	Data Clarity = 0	1.798	1.371	.190
	Data Clarity = 1	4.086	1.405	.004
Covariable	Students on team	-0.030	0.228	.896
	Number of students in class	-0.030	0.065	.651
	Years of SCENIC teacher instruction	1.758	0.691	.011
Cofactor	AQIQ	-0.107	0.674	.874
	SQIQ[a]	0	.	.

RQ3. Application & Focus

Table 7 offers insight into the focus of the student posters. AQIQ posters were very likely to relate to health issues, with 81.5% of AQIQ posters discussing human health. In contrast, none of our 50 SQIQ posters referenced impact on human health. The majority of SQIQ posters (68%) related to agriculture and many (34%) related to conservation. This data shows a sharp contrast between Air Quality and Soil Quality projects. Few posters in either group conducted experiments or discussed applications having to do with wildfires.

Table 7. Number of Student Posters coded for each potential application

School	Year	Poster Type	Potential Application in:			
			Agriculture	Conservation	Wildfire	Healthcare
A_1	2021–22	AQIQ	0	7	0	17
B	2021–22	AQIQ	0	4	0	30
C	2021–22	AQIQ	0	1	0	5
D_1	2021–22	AQIQ	0	6	0	14
D_2	2021–22	AQIQ	0	0	0	9
E	2021–22	AQIQ	0	4	0	35
A_2	2022–23	SQIQ	11	12	1	0
D_3	2021–22	SQIQ	7	0	0	0
D_4	2022–23	SQIQ	16	5	2	0

Discussion

Interpretation

The coding matrix provided a structured way to transform qualitative poster data into quantifiable metrics on student's posters. Despite the "fuzziness" inherent in classifying student work—where some posters showed partial or overlapping elements of different variables—it seems our framework has found statistically significant differences that can help answer our research questions.

Science vs. Engineering

One of the main goals of the SCENIC is to increase Engineering Identity in rural K-12 students. The results of our analysis suggest that student investigations were generally rooted in scientific inquiry (e.g., hypothesis testing, data analysis). This aligns with broader theories of inquiry-based learning [10][11] that emphasize student-driven questions and evidence-based exploration. Within the matrix, many posters demonstrated some engineering content, such as stating a problem or proposing a design or intervention. However, engineering was often manifested as an extension of scientific analysis rather than a structured design cycle (e.g., problem solving, optimization). In other words, students frequently answered "What do we observe?" but only occasionally moved toward "How can we design a solution to improve the situation?" This suggests that while the SCENIC program fosters authentic scientific inquiry, the engineering component is less developed in most cases.

Given that these classrooms were primarily science-specific courses (e.g., chemistry, environmental science), it is unsurprising that many students framed their projects around testing hypotheses and interpreting data rather than developing engineering solutions. The SCENIC program provides mentorship and resources to rural schools, but the curriculum ultimately evolves under a class' purview. The fact that these classes are billed as "science courses" inherently orients projects toward scientific exploration rather than engineering problem-solving.

One important observation is that whether a poster comes from AQIQ or SQIQ has no significant impact on science vs engineering emphasis in the posters. Because Soil Quality Inquiry is a newer arm of SCENIC compared with Air Quality, it was important for us to determine whether these programs reflected any inequity in the function of SCENIC. Our findings seemingly tell us that, so far, the Soil Quality program has been a useful extension of SCENIC, providing at least the same outcomes as Air Quality Inquiry.

Variability in posters' engineering depth may be partly attributable to other factors, notably teachers' experience with SCENIC and classroom size. Our data suggests that, over time, as they gain more experience with SCENIC, teachers may integrate engineering more deliberately into their curriculum, aligned with the goals of SCENIC. Additionally, smaller class sizes also correlate with greater engineering emphasis, which may be attributable to more personal instruction, and therefore direction towards engineering.

Clarity in Data Presentation

One potential measure of engagement with their inquiry projects, and therefore greater impact on our target population, is the quality of data presentation on student posters. We theorize that data clarity could be a good measurement of time spent on a poster, quality of data measurement, and overall engagement with the curriculum.

Our analysis reveals no significant correlation between our measured variables and data clarity except for years of SCENIC teacher instruction. However, different classrooms saw significant differences in outcomes. Together, these observations indicate that the greatest predictor of data presentation quality, and potentially student engagement, is teacher driven.

Focus and Application

While Science and Engineering do not vary across Air Quality and Soil Quality Inquiry, topics that students chose to engage with vary tremendously.

While this may be a result of the types of classes that employ AQ vs. SQ pods, we believe that the type of sensors the different pods use naturally orient students towards topics that easily engage with those measurements. For example, CO_2 levels in classrooms were a commonly studied topic by AQIQ students, while soil moisture in plant soil was common among SQIQ students. Topics of air pollution (and human health) naturally follow from air quality measurements, while soil measurements often deal with agriculture and the environment.

Implications for SCENIC and K-12 Inquiry Education

Our findings offer potential insights on how best to deliver to K-12 rural students.

Firstly, our findings indicate a need for more explicit scaffolding around engineering methods. For instance, teachers could integrate structured mini-lessons on the engineering design cycle, guiding students to identify a design goal, brainstorm solutions, test a prototype, and iterate based on feedback. Since beginning our research, SCENIC has already changed structured prompts on template posters to encourage students to relate their research to an ongoing problem. Further design, iteration, and problem-solving education could be incorporated directly into future SCENIC lesson plans or rubrics, ensuring that engineering thinking is foregrounded alongside scientific exploration.

The importance of teacher familiarity with the SCENIC model—evidenced by our data showing that experience correlated with stronger engineering emphasis and clearer data presentation—points to the value of ongoing professional development. As educators become more experienced with SCENIC, positive outcomes in student posters significantly increase. Increasing instructor education and building familiarity with SCENIC's goals and intended outcomes may contribute to better K-12 rural outcomes. Sharing examples of engineering-focused posters from previous cohorts or offering step-by-step guides for project-based learning may help teachers confidently expand beyond purely scientific investigations. Additionally, increased experience and training may also lead to better student engagement.

One challenge that the SCENIC program has faced is finding its place in mainly science-based high school courses. Teachers are sometimes hesitant to pilot the program when it may not align with their curriculum. We believe that the expansion of the Soil Quality arm of the project, which has grown SCENIC's reach into many more high school classes, is as good a platform to bring engineering into rural K-12 classrooms as Air Quality Inquiry. Having multiple platforms allows greater flexibility for teachers to incorporate SCENIC while staying aligned with their curriculum. The type of pod students receive correlates strongly with the subject matter a student group will emphasize, which may be helpful for teachers who want an emphasis on agriculture, healthcare, etc. Further expansions, including water quality inquiry, and others, would likely maintain the outcomes found in Air Quality Inquiry, while providing greater flexibility to incorporate inquiry-based projects into rural curriculum.

Limitations

As these data are drawn from student-authored posters, there is often incomplete or inconsistent detail regarding methods, analyses, or design considerations. Some posters lacked sufficient clarity or depth—either because of time constraints, instruction style, or student familiarity with technical communication. Consequently, inferences about the degree of engineering design or scientific rigor may not always fully reflect students’ underlying knowledge or intentions.

A fundamental constraint is that most participating classes were primarily designated as science courses (e.g., environmental science). By definition, their curricula and teaching styles emphasize scientific inquiry and objective study rather than engineering design and problem solving. This context biases the nature of student investigations and the extent to which they apply engineering skills. Even if students gain engineering identity, the science-focused environment inherently shapes how students present their projects, which biases our data against engineering outcomes.

Additionally, student attitudes are hard to measure in posters, which led to a reduction in the original scope of our study. We had intended to measure student affect and research connection to local place and a rural context. While certainly a worthwhile investigation, these attitudes are challenging to measure in student posters, leading to low incidence of direct measurement. This led to us dropping this variable in our final research.

Conclusion

Summary of Main Findings

In analyzing 185 posters from the SCENIC Colorado program, our coding rubric revealed that most students produced work leaning more heavily toward scientific inquiry than engineering design. Although some posters demonstrated elements of the engineering design process, most were primarily hypothesis-driven and focused on interpreting data rather than proposing or prototyping solutions. Teacher experience with SCENIC was positively associated with both greater engineering emphasis and clearer data presentation, highlighting the importance of instructor familiarity in successfully integrating engineering concepts. Importantly, there were no statistically significant differences between the Air Quality Inquiry (AQIQ) and Soil Quality Inquiry (SQIQ) arms regarding the depth of engineering content and student poster data clarity, which we believe indicates equity in student engagement.

Practical Takeaways

- **Integrate Engineering Scaffolds:** Including explicit instruction on the engineering design cycle (e.g., defining problems, iterating prototypes, evaluating solutions) can help students move beyond purely scientific investigations and deepen their understanding of engineering processes.
- **Leverage Teacher Experience:** Teacher experience with SCENIC raises both overall project quality and student engineering outcomes. When teachers feel confident in facilitating engineering-based learning, students benefit by producing higher quality data with a greater engineering emphasis. By providing ongoing support to current teachers and development opportunities for new teachers to familiarize with the program, we may see better outcomes aligned with SCENIC's goals.
- **Different Pod, Similar Outcomes:** Although AQIQ and SQIQ naturally steer students toward different real-world applications (healthcare vs. agriculture), both platforms foster

comparable levels of scientific and engineering thinking. This suggests that teachers can select the pod type that aligns best with course content without sacrificing the program's broader inquiry-based goals. This also provides opportunity for SCENIC to continue expansion to water quality inquiry and more, with the goal to provide greater opportunities for teachers to incorporate inquiry-based learning into curricula.

Future Research and Work

Additional research could investigate how best to measure and foster students' engineering identity—an outcome that may not be fully captured by analyzing posters alone. For instance, supplementing poster evaluations with student interviews and pre/post surveys could reveal deeper insights into students' attitudes and problem-solving approaches. We also recommend investigating how greater scaffolding changes engineering outcomes among students, such as by changing the poster template and/or more in-class discussion. Finally, longitudinal studies that track the same teachers over multiple years would help disentangle how greater familiarity with SCENIC influences student outcomes and more firmly establish effective practices for integrating engineering design in rural K–12 science classrooms.

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