The Impact of STEM Enrichment Opportunities on Secondary School Students

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***Abstract* – Attracting and retaining talented students is a central issue in freshman engineering education and can be impacted by experiences prior to college. We argue that Governor's Schools, which are state-wide summer enrichment programs to engage talented middle school or high school students in a focused college-style curriculum, are useful models from which important insights about college and career choices can be gleaned. This paper focuses on the Pennsylvania Governor's School for the Sciences (PGSS), a Science, Technology, Engineering, and Mathematics (STEM) enrichment program that graduated nearly 2400 students over a 27-year-period. We review the history and structure of PGSS and provide evidence of its similarity to a freshman engineering curriculum. We demonstrate the measurability of PGSS's impact by presenting outcomes from a recent alumni survey. Results illustrate the effectiveness of PGSS to inspire enthusiasm for STEM, and reveal program components that correlate with high retention in STEM majors through college. Finally, we argue for the value of PGSS and similar programs as venues for career exploration and recruitment into STEM fields.**

Index Terms – Governor's school, science education, student research, first year engineering education

INTRODUCTION

High school students are often not exposed to engineering coursework before they enter college. The transition to collegiate engineering programs can be better facilitated by informing students and their families about the expectations and critical skills needed for success [1]. High school students sometimes must search outside their schools for the resources to help discover or refine their interest in engineering. Governor's Schools are one way for students to explore future careers through exposure to university level faculty, coursework, laboratories, and research.

BRIEF HISTORY

The first Governor's School was created in 1963 in North Carolina, in order to provide gifted students statewide a summer residential academic experience with educational opportunities beyond what individual school districts could offer [2]. This idea quickly spread to other states as similar programs were instituted nationwide [3]. While some programs maintained a broad curriculum, others became specialized in areas such as arts, health care, and the sciences. Recent budget shortfalls due to economic circumstances have reduced state funding in many cases, forcing some programs to close [4,5,6]. Others continue to exist, but rely on private donations or tuition and have thus dropped the term "Governor" from their titles [7,8,9]. As of 2011, Governor's School programs remain in over 20 states, including Arkansas, Kentucky, Mississippi, Missouri, New Jersey, North Carolina, North Dakota, Texas, West Virginia, and Vermont [10]. In the 1980s, as the number of states with Governor's Schools grew, administrators saw a commonality of purpose and advantages of sharing successes and failures. In 1987, the first annual meeting of the National Conference of Governor's Schools (NCOGS) was held in Little Rock, Arkansas. NCOGS continues to meet annually in various states.

The first Pennsylvania Governor's School program (for the Arts) was founded in 1973 [11]. In the early 1980's, the state recognized a need to promote involvement in the sciences, and in 1982 the Pennsylvania School for the Sciences was opened at Carnegie-Mellon University (Pittsburgh, PA) through a combination of public and private funds. In 1983, the PA Department of Education assumed full funding of the program, which was renamed the Pennsylvania Governor's School for the Sciences (PGSS). The program ran successfully for 27 summers and graduated 2,378 students. In early 2009, all state funding was cut to the eight Pennsylvania Governor's schools, including PGSS [12].

PGSS's cancellation mobilized alumni of the program to form the PGSS Campaign (originally named the PGSS Alumni Association), a 501(c)(3) nonprofit. Their goals are to promote STEM education and to ultimately restart the program through multifaceted efforts [13,14]. The PGSS Campaign has re-established contact with most alumni and begun gathering information to assess the impact of PGSS. In the process, the Campaign has received numerous testimonials about the impact PGSS has had on alumni, both professionally and personally [15]. Data presented in this paper come from records maintained by the PGSS Campaign and a recent alumni survey.

PGSS STUDENT SELECTION PROCESS

PGSS hosted an average of 90 students per year between 1982-2008, with a minimum of 52 students in 1982 and a maximum of 100 students in 2008. Typically over 500 students applied annually. The PGSS faculty would review

all applicants and rank them based on factors including grades, SAT/ACT, science activities, recommendations, and essays. Applications were sorted geographically by the students' Intermediate Unit (IU) in Pennsylvania, with at least one qualified student selected from each of the 29 IUs. This promoted geographic diversity and allowed students from rural communities and other areas with less access to resources to be competitive. An effort was also made for gender balance in each class, with most years achieving a male-female ration near 1:1. Because PGSS was fully funded and attendees received a full scholarship, students that were selected could attend regardless of socio-economic status [16].

PGSS STRUCTURE AND CURRICULUM

PGSS was a five-week residential intensive introductory college experience for students who had just completed their junior year of high school [16]. Students arrived on a Sunday morning and completed a day-long orientation. Beginning the second day of the program, students were immersed in a full-time academic curriculum with core courses and electives (Table I)

TABLE I
PGSS WEEKDAY CLASS SCHEDULE (WEEKS 1-4)

7:00 am	Breakfast
8:00 am – 12:30 pm	Core courses: Biology, Chemistry, Computer Science, Math, Physics
12:30 pm – 1:30 pm	Lunch
1:30 – 5:30 pm	Electives and lab courses
5:30 – 6:30 pm	Dinner
6:30 – 8:30 pm	Electives, seminars, special events
8:30 pm – Midnight curfew	Study time in residence halls

On any given weekday during the first 4 weeks of the program, a student would spend 7 to 10 hours in class or lab. Exact course descriptions varied each year depending on the faculty, but overall subject structure and educational methods remained consistent for the duration of the program [17]. Evenings and weekends were left free for completion of homework and recreation.

Core courses were Biology, Chemistry, Computer Science, Mathematics and Physics. Four of the five courses were offered each day on a rotating schedule, resulting in 16 hours of instructional time per course. Each course assigned 2-4 problem sets which were challenging and typically could not be completed without assistance from teaching assistants or other students. For many PGSS students this was the first time they ever needed to ask for help with their homework.. It encouraged students to collaborate, discuss concepts interactively and build confidence to seek help when needed.

Concurrently, students began to work in teams on a capstone research project, mentored by a faculty or an experienced graduate student with the help of a PGSS teaching assistant. While attending courses in weeks 1-4, students began to acquire background information for the project, conduct experiments, and collect and analyze data. The fifth and final week of PGSS was dedicated solely to the project, with the objectives of composing a journal publication and creating a power point presentation, to present at a research symposium at the end of the week. Around 300 research projects were completed by PGSS students and published in the PGSS Annual Journal, which is publicly available on the PGSS Campaign website [18]. Projects titles include:

- The Lactose Operon: An Analysis of Gene Regulation in Escherichia Coli (1982)
- Deviations of Asteroidal Orbits in Resonance with Jupiter (1985)
- Determination of Radioactive Sources in Orange Fiestaware and Mellon Institute Brick (1988)
- An Anthropological Application of Group Theory (1991)
- An Artificial Life Simulation Using Two-Dimensional Turing Machines (1994)
- Effects of Splicing Factor Interactions on the Ultrabithorax Phenotype in Drosophila melanogaster: A Synthetic Lethal Screen for Proteins that Interact with B52 (1997)
- Velocity Dependence of Drag on a Liquid Nitrogen Droplet Exhibiting Leidenfrost Behavior (2000)
- Fulleropyrrolidines: Amino Acid and Aldehyde-Functionalized Buckminsterfullerenes (2002)
- Effects of Natural and Synthetic Antioxidants on Oxidative Stress in the Medicinal Yeast S. Boulardii using Atomic Force Microscopy and Viability Assays (2005)
- Effects of Chemical Substitutions on Oxide Superconductors (2008)

Although PGSS was primarily an academic program, a unique feature was college-style residence in a dorm on the Carnegie-Mellon campus. To foster a sense of community and encourage students to be sociable, at least one unique group activity was planned per day, generally in the evening after classes. The first social event of the program, a square dance, was required of all students to push them out of their comfort zone at least once. Other social activities included science-themed renditions of popular game shows (e.g. Double Dare and Win, Lose, or Draw), dances, sports competitions, a casino night, and a talent show. Weekends permitted additional free time to socialize or participate in chaperoned trips off campus to museums, sporting events, and other events in Pittsburgh. Because many intellectual students find social interactions awkward and uncomfortable, the social program aimed to build a community of teamwork and collaboration.

PGSS AS A MODEL TO STUDY FRESHMEN ENGINEERING CURRICULA

Challenges in freshman engineering education are not only to recruit talented students to the engineering profession, but to maintain their commitment to engineering into the upperclassman years, since over half of students who start an engineering baccalaureate do not finish it [19]. Improving traditional curricula is an area of active research;

however systematic alternatives may be difficult to implement on an institution-wide level [20]. Assessing impacts may require periodic surveys throughout the undergraduate years and after graduation, meaning that there will be a long latency between when changes are implemented and their impacts are fully measured.

We suggest that the Pennsylvania Governor's School for the Sciences and similar STEM programs are models that can be studied analytically for insights into how to enhance engineering freshman curricula. By virtue of its structure PGSS exhibited many signatures of an engineering education. Completion of the PGSS program meant that a student has excelled in several areas that have been identified as pre-college characteristics important for engineering student academic success and retention in college: academic achievement, quantitative skills, study habits, commitment to career and education goals, confidence in quantitative skills, and social engagement [21]. Students admitted to PGSS typically demonstrated strong scientific curiosity or achievement. Hosted on the college campus of Carnegie-Mellon University, it featured instruction from college faculty, and provided focused, hands-on exposure to STEM research. Academics were rigorous, with homework stressing critical thinking and analytical problem solving. Core courses, in Chemistry, Computer Science, Mathematics, and Physics are representative of requirements for many freshman engineering curricula. Electives provided focused immersion in many areas considered to be sub-disciplines in engineering, such as lasers, material science, and computational problem solving. In addition, the capstone project provided opportunities to conduct research at a high standard and present it to their peers in the form of an academic symposium.

Considering structural similarities between PGSS and college, it can be expected that a survey of Governor's School alumni can offer a wealth of relevant data that can be applied to a first year engineering program. If it can be demonstrated that programs like PGSS graduated alumni that remained engaged in STEM fields, colleges may be able to replicate aspects of the program to improve the first year experience. We submit that key program features that correlate well with future STEM interest can be deduced by analyzing survey data.

SURVEYS AND METHODOLOGY

We designed an online survey to learn about current activities of PGSS alumni, measure their attitudes about science, and assess certain aspects of PGSS from when they attended as students. Between November 2011 and January 2012, PGSS Campaign invited alumni from all classes (1982-2008) to participate. As of January 2012, responses had been received from 593 alumni.

All respondents answered the following required questions:

- Personal information (name, gender, PGSS class year, email address, where you live)
- Highest level of education completed? (High school, Bachelor's, Master's, Doctorate (Ph.D., JD, MD), Other)
- Are you currently in an academic program? What degree level? (Not currently enrolled in a program, Attending school for a Bachelor's now, Attending school for a Master's now, Attending a doctoral program now, other)
- On a scale of strongly negative (1) to strongly positive (5), how did PGSS affect the following?
    - Your overall interest in science
    - Your interest in pursuing a degree in STEM field
    - Your interest in attending graduate school (Master's, MD, JD, Ph.D. or equivalent)
    - Your interest in a career in STEM
- Where did / do you attend UNDERGRADUATE school (mark NA if not applicable)?
- Please list any college majors and minors that you have completed or are pursuing now (including year, degree (e.g. BS, BA, minor), and subject area
- Did PGSS influence your choice of undergraduate school, and your choice of major(s)/minor(s)? Please explain.
- Where did / do you attend GRADUATE school (mark NA if not applicable)?
- Please list any graduate degrees you have earned or anticipate earning (including year, degree , subject area)
- What is your current occupation? If you'd like, please include information about where you are employed.
- Please describe a little about your work and to what extent, if any, it is related to STEM.

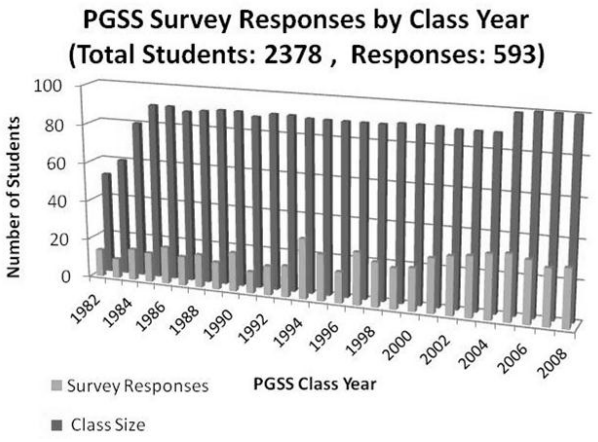

FIGURE 1
PGSS GRADUATING CLASS SIZES AND CLASS RESPONSE RATES TO THE ALUMNI SURVEY

For survey questions in which respondents ranked a response on a scale of 1-5, a mean value of the sample can be calculated, and the standard deviation of the data (σ). For questions in which a percentage responding to a binary query can be identified as a percentage responding affirmatively (p) and the rest being negative (1-p) a separate treatment can be used to assess error. The confidence interval or standard error ($\sigma_{p\text{-}s}$) for a proportion (p) of sample population (n) at a 95% confidence level (Z = 1.96) to be [22,23]

$$\sigma_{p-s} = \pm Z\sqrt{\left(\frac{p(1-p)}{n}\right)} \qquad (1)$$

After required questions were answered, we invited respondents to complete optional follow-up questions. The free response format of these questions allowed alumni to provide testimonial and anecdotal statements, and otherwise voluntarily describe specific features of the program that were significant to them:

- Please describe how PGSS has influenced your life.
- What, to you, were the most important features of PGSS? Please explain.
- Have you been involved in any science outreach or volunteerism? If so, please share your experiences.

The number of responses to a given optional question varied between 180 and 270 (out of 593 total survey responses).

RESULTS

A primary objective of our survey was to measure continued engagement of PGSS alumni in STEM fields by asking three lines of questions: 1) What is the ultimate educational level of alumni, 2) How many alumni subsequently majored or minored in science and engineering during college, and 3) How did PGSS influence alumni attitudes about science and higher education?

Based on PGSS Annual Reports and PGSS Campaign alumni database, we were aware of the college decisions of 1820 alumni (Table II). The margin of error for extrapolating the percentage to the entire alumni population was computed using the percent that went a particular school (p) and the percent that did not (1-p) at a 95% confidence level. The host organization, Carnegie Mellon University, attracted nearly 10% of the graduates of PGSS. The table reveals that the most popular college destinations for graduates of PGSS are Ivy League and top tier research institutions.

TABLE II
TOP SIX UNDERGRADUATE DESTINATIONS FOR PGSS GRADUATES, BASED ON ALUMNI ASSOCIATION RECORDS, DECEMBER 2011, WITH 1820 STUDENT'S COLLEGE CHOICE KNOWN OUT OF 2378.

Undergraduate School	Known # of PGSS graduates attended	As a % of sample size (n= 1820)	+/- Margin of error for population
Penn State	170	9.3%	1.3%
Carnegie Mellon	157	8.6%	1.3%
MIT	135	7.4%	1.2%
U Penn	132	7.3%	1.2%
Harvard	129	7.1%	1.2%
Princeton	112	6.2%	1.1%
Total	835	45.9%	2.3%

We then considered the highest levels of education sought by alumni. For this measurement, we excluded students still in undergraduate or graduate programs and considered only responses from students who had been out of high school 10 years or more (PGSS classes 1982-2000). Based on responses from the 346 respondents that meet this criterion, statically, 88.2% (± 3.4%) of PGSS graduates will earn graduate degrees, with 60.4% (± 5.2%) earning doctoral or terminal degrees in their field.

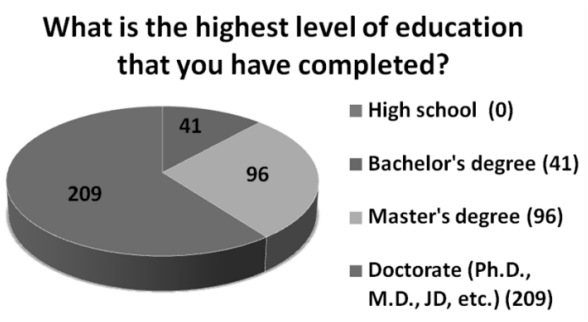

FIGURE 2
HIGHEST DEGREE EARNED BY PGSS ALUMNI WHO HAVE BEEN OUT OF HIGH SCHOOL 10 YEARS OR MORE (CLASSES OF 1982-2000) BASED ON 346 SURVEY RESPONSES

Assuming that alumni graduating PGSS from 1982-2000 have had ample time to complete school and join the workforce, 92.8% (± 2.7%) now work in STEM fields.

Attitudes of the entire sample of respondents (n=593) were assessed on a scale of 1 (strongly negative) to 5 (strongly positive). The majority of alumni (74.5% ± 3.5%) believe that PGSS had at least a positive effect on their decision to pursue graduate school (Figure 3). Figure 4 shows that the overwhelming majority of alumni (95.6% ± 1.6%) stated that PGSS had a positive effect on their interest in science, with 73.5% (± 3.6%) indicating a strongly positive impact. Figure 5 shows a high correspondence between PGSS attendance and interest in studying STEM fields, with 91.9% (± 2.2%) of students indicating that PGSS positively influenced them to pursue a STEM degree. A similarly high correspondence with STEM career participation is shown in Figure 6, with 87.4% (± 2.7%) of PGSS graduates positively encouraged to seek employment in STEM fields.

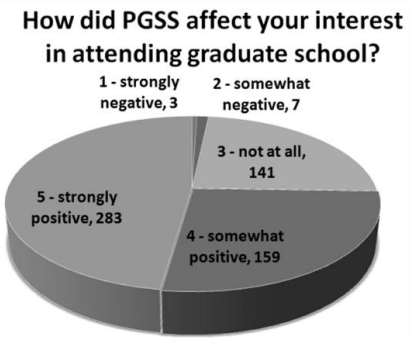

FIGURE 3
EFFECT OF PGSS (1982-2008) ON STUDENT INTEREST IN GRADUATE SCHOOL (AVERAGE SCORE OF 4.20, STANDARD DEVIATION OF 0.88)

We therefore claim that PGSS was highly successful in fostering enthusiasm toward science and engineering, and promoting advanced studies and careers in STEM fields.

Given the efficacy of PGSS, we asked what features of the program made the strongest impression on alumni. This information was elicited through the optional free-response

question: "What, to you, were the most important features of PGSS? Please explain". Although all data were unique, we were able to uncover a number of emergent themes with manual classification (Table III). We note that many respondents identified more than one factor as important.

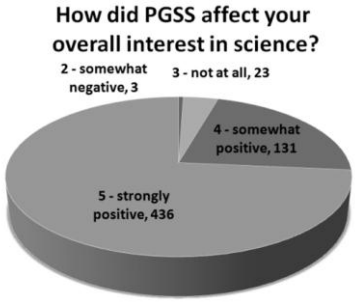

FIGURE 4
EFFECT OF PGSS (1982-2008) ON INTEREST IN SCIENCE (AVERAGE SCORE OF 4.69, STANDARD DEVIATION OF 0.57)

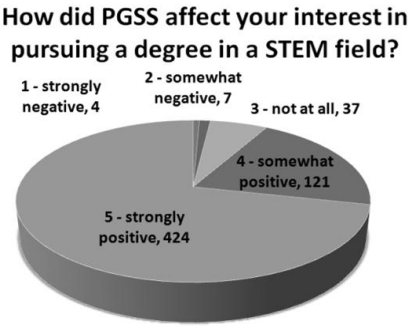

FIGURE 5
EFFECT OF PGSS (1982-2008) ON ENCOURAGING STUDENTS STUDY STEM SUBJECTS (AVERAGE SCORE OF 4.61, STANDARD DEVIATION OF 0.72)

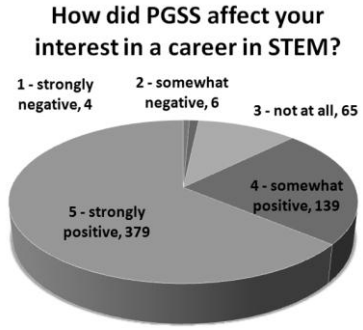

FIGURE 6
EFFECT OF PGSS (1982-2008) ON ENCOURAGING PURSUIT OF CAREERS IN STEM FIELDS (AVERAGE SCORE OF 4.49, STANDARD DEVIATION OF 0.78)

We concluded that the salient features of PGSS could be broadly classed in terms of academic coursework, or the content and administrative policies of core and elective classes; quality and availability of mentorship by instructors and TAs; camaraderie and social aspects; and the hands-on research projects. Once broad themes were identified, we extracted further details from the free responses to pinpoint specific strengths. Under "Subcategories", we display strengths noted by at least 10% of respondents who identified the corresponding main feature in their response. Many students identified multiple factors in one response.

TABLE IIII
MOST IMPORTANT FEATURES OF PGSS, FROM OPTIONAL QUESTION #2. (PERCENTAGE BASED ON 269 TOTAL RESPONSES)

Main Feature	Subcategories	Percentage of Occurrence in Responses
Coursework	Challenge	**48.0%**
	Course selection	
	Nontraditional topics not in high school	
	Collaborative and non-competitive philosophy	
Mentorship	Teaching Assistants	**21.6%**
	College Faculty	
Camaraderie	Like-minded peers	**70.3%**
	High quality of students	
	Social program and dorm life	
	Networking / long term outcomes	
Research Project		**27.9%**

Having determined key features of the PGSS program, we asked whether there were any parallels to a student's choice of studies later in college, with special interest in alumni who majored or minored in engineering. We focused on the research project, for the twofold reasons that the undergraduate laboratory experience is a topical issue in education [24], and a complete record of PGSS research projects is available. Using the surveys, we identified all alumni known to have majored or minored in engineering, and determined the topics of their research by referring to the catalogue of PGSS Annual Journals (Table IV)

TABLE IV
PGSS ALUMNI THAT MAJORED OR MINORED IN ENGINEERING IN COLLEGE (145 OF THE 593 RESPONSES), AND THEIR PGSS RESEARCH AREAS (B: BIOLOGY, C: CHEMISTRY, CS: COMPUTER SCIENCE, P: PHYSICS, M: MATH)

	B	C	CS	P	M	Total
Biomedical	3	4	3	4	0	14
Chemical	5	**17**	2	7	3	34
Electrical/Computer	2	4	**18**	**15**	4	43
Mechanical/Aerospace	0	0	3	**15**	4	22
Materials/Metallurgy	0	2	0	4	1	7
Civil, Geological, Environment	1	1	0	3	0	5
Engineering Physics/Mechanics	0	0	2	4	0	6
Industrial, App. Math, Other	1	4	1	7	1	14
Totals	12	32	29	59	13	145

Students who studied engineering in college tend to have chosen computer science and physics research projects while at PGSS (~60%). A Pearson's χ^2 test of Table IV suggests that a student's PGSS research topic and the particular engineering discipline this student would subsequently study in college are related ($\chi^2 \approx 64$, df = 28, $p < 0.01$). This correspondence appears to be especially pronounced for Chemical Engineering, Electrical/Computer Engineering, and Mechanical Engineering.

CONCLUSIONS

The Pennsylvania Governor's School for the Sciences (PGSS) was a highly successful program, as evidenced by the number of applicants and the accomplishments of the graduates. Alumni surveys reveal a significant impact on encouraging higher education and careers in STEM fields.

Many alumni identify the rigorous, yet collaborative, college-level curriculum, the mentorship, camaraderie, and research as influential factors in their future development.

Clearly, PGSS created an environment where intellectual achievement and education were highly valued. For many students this provided an acceptance from their peers that allowed them to be comfortable exploring their educational interests. Further, among students who became engineers, there is a very strong correlation between future specialty and the topic of their early research experience. Together, these results may suggest that a program that encourages collaboration and high achievement among students with similar interests, provides mentorship, and engages students in basic research relating to the discipline of interest may attract or maintain interest in engineering.

PGSS deserves to be restored and even expanded to other states, because of its record of impact and its potential value as a model to study effective techniques for exposing teenagers to college-level science and engineering.

ACKNOWLEDGMENTS

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