Engineering an Evaluation for a Growing Rocket Program: Lessons Learned

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Abstract

This project involved examining the construction of an evaluation for a high school rocket program. The goal was to create an evaluation that would demonstrate program effectiveness in terms of student satisfaction and confidence in their ability to apply pre-engineering concepts in the building of rockets. This case study provides an in-depth study of the challenges and milestones faced by the evaluation team. One challenge was understanding the unique engineering design-based curriculum. Another challenge was exploring the impact of a pure inquiry-based teaching program. One key milestone reached was creating a participatory environment for the program evaluation. The result was an evaluation regime that was useful to the rocket program stakeholders.

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Introduction

Perennially, educators, industrialists, social commentators, and politicians call for science, technology, engineering, and mathematics (STEM) instruction that matches an increasingly multifaceted global economy. In the U.S., this new economy presents a growing demand for STEM talent. However, current test-driven curricula and instructional practices in American schools cannot meet the challenge. The latest results from the Trends International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) show American students lagging behind other industrialized nations. Additionally, rationales for new approaches can be found in *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Interestingly, for the past decade, one high school STEM education program has maintained a commitment to addressing these concerns. This effort has students' conceiving, building, and launching rockets in an inquiry-, discovery-, and problem-based classroom.

This rocket program aims at increasing high school student interest in STEM by having students use their own efforts to make rockets fly. The basic rockets must be designed to carry a one pound payload a mile high. The top level rockets built by students are flown from White Sands Missile Range, and they travel over 100,000 feet, reaching transonic speeds. Students get nine months of hands-on engagement that includes learning from direct and scholarly research, theory development, design brief creation, and post mission analyses. The curriculum also emphasizes soft-skills, like teamwork, communication, and leadership. Teachers work as roving facilitators whose goal is to help students "to see beyond the fire and smoke" and use data to direct effort. These teachers represent about 50 high schools in this Southern state. They are taught to use Socratic teaching methods, with a focus on formulating good questions that lead students to discovery across a range of topics that include those from aeronautics, electrical engineering, and fluid dynamics to those in algebra and calculus. Program staff also collects many anecdotes of program alumni being directly recruited by postsecondary engineering departments. Additionally, the program now has alumni who have done well and work for SpaceX, NASA and Jet Propulsion Laboratory. How does one evaluate such a program?

Purpose

This paper describes the evolution of an evaluation strategy for this unique approach to STEM education. The reader should note that as a case study, this paper will have a different organizational format than one might normally expect. The focus of this report is on the evaluation strategy and methods, rather than program outcomes. After the introduction and purpose here, 1) we report a summary of the program outcomes, 2) a description of the external evaluation, 3) key analysis, and 4) conclusions. First we report the results, then the rest of the paper is a description of how we produced the results. The true outcomes here are our methods.

Clearly, systematic approaches to reflecting on and investigating educational programs can improve practice and contribute to the knowledge base in various disciplines[1]. This evaluation was one such systematic effort. From the first meeting with stakeholders, the lead evaluator worked to establish trust with the program directors. He made it clear that the focus and purpose of the evaluation was program improvement and that the evaluation team would strive to be transparent and unobtrusive. He included the program directors into each aspect of evaluation strategy, making sure that this strategy stayed consistent with the program's mission, and that it followed the principle of keeping the evaluation out of the way of running the program. The evaluation strategy included four parts. The first was an exploratory evaluation. This effort was based on past data and interviews with stakeholders. It resulted in a good baseline picture of where the program was in 2014. Second, the evaluators created an evaluation plan. Aligned with the exploratory evolution, the evaluation plan presented a program logic model, solidified program stakeholder and evaluation team roles, provided preliminary questionnaire maps, laid out an implementation strategy and defined evaluation products. It also laid out an agreed upon timeline for deliverables. Third, the strategy included an annual evaluation of student and teacher opinions of their experiences. Finally, the strategy sketched the future architecture for an ongoing, real time assessment system using a custom-designed social networking service. This paper will share the lessons learned that apply to evaluating STEM pedagogy and STEM programs that use nontraditional approaches and assessments. Therefore, this paper is a case study that provides a rich description of the processes involved in the development of an evaluation of this rocket project.

Evaluation of SystemsGo's Rocket Project: The SystemsGo Effect

The following is a summary of the evaluation taken from the annual report[2]. Beginning with the end in mind, this summary is the result of our evaluation effort. SystemsGo is a program that helps students acquire 21st Century science, technology, engineering, and mathematics (STEM) workforce skills. What follows is a brief summary of findings, conclusions and recommendations based up Academic Year (AY) 2015. This program is poised to expand to multiple states. This summary is the end result of the evaluation planning process, which included several meetings, observations of teachers and students, interviews, and student and teacher questionnaires.

- Four hundred and sixty (466) Texas participants answered a questionnaire about their experiences following the program's annual major culminating event, the launching of rockets in May 2015.
- These students were positive about the experience. In some cases, they were spectacularly positive.
  - Participants had strong confidence that they would attend college.
  - Participants were very positive about their chances of excelling in a STEM career.
  - When it came to speaking positively about the rocket program experience, 45% of the total scored the experience a 100, on a 100-point scale.
- In a comparison of program means across all administrations of similar questionnaires, the responses yielded similar high results. High positive ratings in the fall may be an indication that students have high expectations for the program at the start of the year. This may mask actual learning effects.
- From the open-ended questions, it appears that participants love the notion of learning from failure.
- Additionally, in comparison to earlier evaluations, students have a much more specific wish list for program improvements, with better equipment leading the list.
- Finally, when participants were asked about STEM "hard" concepts they learned, they reported an impressive list that included topics from physics and aeronautics.
- Overall conclusion: This program was typically effective in AY2015, and this is just one moment in a long line of reports indicating an effective outcomes. However, AY2015 provides evidence that the program is probably more effective at deeper cognitive levels than current evaluation methods can capture. The effects are so strong that the principal investigator (PI) dubbed the stellar survey outcomes "the SystemsGo Effect."
- Recommendations: Program stakeholders should launch a student tracking system as soon as feasible. A line of research projects examining various aspects of the program that use experimental and quasi-experimental designs should commence now.

How the Evaluation Team Produced the Evaluation Summary: Description of the External Evaluation of SystemsGo's Rocket Project

In the August of 2013, SystemsGo contracted with Texas Tech University to prepare a summative, external evaluation. According to Gall, Gall, and Borg[3], summative evaluations help establish the merits of a fully operational program. The external evaluator represents the interests of stakeholders who will see the final report and use it to make decisions about the program. These decisions can be high stakes, including hiring firing, funding allocation, strategic planning, and curriculum redesign. In the case SystemsGo, the principal investigator was a professor of educational psychology, and the stakeholders are the board chairperson, the director and founder of the project, and organizations and other persons who provide funding to the program. All of the program's funding comes from private foundations. This evaluation project started with two phases, one divergent and the other convergent. These phases actually reflect the two types of evaluation questions that guide educational evaluation projects[4]. The resulting evaluation plan included the overarching evaluation questions, descriptions of the roles of stakeholders, and a map of the primary questionnaire used for evaluation of the program.

Divergence: An Ethnography for SystemsGo. Interestingly, the implementation of the evaluation plan began mirroring the engineering design process used by the program. Bridging the divergent and convergent aspects of the evaluation was the production of an exploratory evaluation. An exploratory evaluation is used to help identify and prioritize the specifications for implementing the evaluation[5]. It is based upon existing data and observations made at the beginning of an evaluation period. The evaluation team used the rapid feedback type of evaluation that included an assessment of program effectiveness and options for a summative evaluation. One conclusion from the exploratory evaluation was the need to track program alumni. Overtime, it became clear that a tracking system will need to be engineered by first identifying the need and constraints, researching the problem, developing possible solutions, selecting a promising solution (planning), creating a prototype, testing and evaluating the prototype, then improving and redesigning as needed[6]. The tracking solution for SystemsGo is still being engineered.

The divergent phase of evaluation was a critically important feature to understanding the mission and core principles driving the program included an initial meeting with the program director, the assistant director, and the chairperson of the board of directors for an entire day. This day was spent understanding the program from an ethnographic perspective. This perspective requires understanding how those involved in the program see its mission traditions, values, and future. It also involves purposefully looking for explicit and implicit patterns in behavior of stakeholders and participants. When meeting with SystemsGo personnel, the discussion evolved as those involved provided the evaluator history, anecdotes about former students (particularly success stories), minutes of board meetings, presentation materials, handbooks for teachers, access to a teacher blog, access to key individuals in the community who could provide information about the program, contact information for teachers who participate in the program, and past external evaluations. They did not, however, release the curriculum that they consider to be a proprietary product. The lead evaluator also spent a day observing teacher professional development. This included instruction on the content to be taught students, safety issues, and SystemsGo teaching methods. These are heavily imbued with inquiry and Socratic teaching methodologies.

During the discovery, “divergent” phase of the program, it became clear that the context of the program is important, and one foci of context demands a holistic and realistic world view about the program being evaluated[7]. Vo and Christie[8] argue that it is important to understand how various systems work together. This program had various communities, each its own system, successfully interacting in order to support the program. In looking at the program from a 20,000 foot view, it became immediately clear that the success of the program was guaranteed by contributions from educators (teachers and administrators) not directly affiliated with the program, local citizens in the SystemsGo community, first responders who donated their time at the launch sites, private citizens who made small donations directly to various participating high schools, and volunteers who drive and even fly in for the annual launches.

Convergence: Positivistic and Postpositivistic Considerations for SystemsGo and Tracking. Positivists posit that the aim of science is objective truth that is the result of direct observation and measurement (Vo & Christie, 2015). Following this research paradigm, researchers try to establish controlled environments to study. They also seek to understand the causes that lead to an effect, using methods like random selection and assignment and experimental designs. However, in the world of evaluation, in general, and in the SystemsGo classroom in particular, there are just too many interacting systems that make the program work. Therefore, the PI recommended setting up a system (multiple databases) to observe the system. To understand the effect of this program requires multiple methods and multiple measures. The evaluation team planned on looking at the program from multiple perspectives using methods like causal-comparative, experimental and quasi-experimental, direct observation, and ethnography are being used X as an organic system. While gaining an outsider's understanding the program required a qualitative approach, mapping the long-term evaluation relied heavily upon planning to develop databases that could store data about program participants—students, teachers, and volunteers), alumni, donors, and interested observers. The idea was to push data into the databases then mine those data to answer a variety of questions. These questions range from those typical of program evaluation to keeping donors and volunteers engaged throughout the year. In planning the databases, it became clear that thinking about data as something fixed is misleading. Across time, as more data are collected, and previous data collections inform later data collections, these databases are themselves interactive and organismic. For this reason the evaluation plan was considered to be a living document that would be updated annually and lay the foundation for an evaluation *strategic plan*. The evaluation strategic plan would be one that would outline an evaluation strategy over time.

Evaluation Plan. The evaluation plan captured both the divergent and convergent considerations mentioned above. Key aspects of the plan were the evaluation objectives and questions, logic model, methodology, and questionnaire map.

The evaluation questions were broad and each had several sub-questions that identified the objects of the evaluation and the measurement tools to be used. In the objectives section of the evaluation plan also included indicators and program evaluation standards that would help the stakeholders know when the program was effective. The objectives, indicators and standards are listed as follows:

1) SystemsGo's participants will finish the program with significantly improved attitudes toward STEM related fields and careers. (statistically significant gain score)
    a) Significantly more positive attitudes and beliefs about STEM-related fields at the end of the program.
        i) Pre/post attitudinal survey; key interviews, observation
    b) Significantly more positive self-efficacy when faced with a STEM-related problem.
        i) Pre/post attitudinal survey; key interviews, observation
    c) Significantly improved intentions to take STEM-related courses after the program.
        i) Pre/post attitudinal survey; key interviews, observation
    d) Significantly improved self-efficacy in regard to 21st century skills

2) SystemsGo's participants will finish the program with significantly improved 21st century skills, including teamwork and collaboration, communication, leadership, and problem solving. (reaching some pre-determined criterion)
    a) Exhibit significantly more positive teamwork and collaboration skills.
        i) Teacher observation rubric
        ii) Student self-evaluation
    b) Significantly increased STEM-related writing, speaking, and presentation ability
        i) Communication rubric—rating of effectiveness of selected products/moments
    c) Significantly increased leadership skills
        i) Reaching high criterion on leadership rubric
    d) Significantly increased problem-solving ability
        i) Teacher observation rubric
3) SystemsGo's teachers will effectively employ 21st Century teaching methods. (reaching some pre-determined criterion)
    a) Teachers effectively use indirect teaching methods, particularly the integration of collaborative and project-based teaching methods.
        i) Observation, self-evaluation, interviews
    b) Teachers effectively integrate technologies into instruction.
        i) Observation, self-evaluation, interviews
    c) Teacher effectively provides feedback to students
        i) Student survey of instruction
        ii) Observation, self-evaluation, interviews
    d) Teacher effectively use techniques that sustain student attention and interest in topics and projects.
        i) Observation, self-evaluation, interviews
    e) Teacher efficacy will be improved.
        i) Observation, self-evaluation, interviews.

The logic model below in Table 1 for SystemsGo's rocket program showed the relationship among the many moving parts in the program. There are two views of it here, as a table and as a z-chart.

Table 1. Logic Model for SystemsGo

Resources	Activities	Outputs for Students and Teachers	Short-Term Outcomes	Long-Term Outcomes
-Private funding -Community fundraisers -Key external stakeholders (e.g., SpaceX) -Volunteer time (mechanical trades professionals) -Knowledge of founders	Teacher training—Socratic and inquiry based methods Project goals • Tsiolkovsky • Oberth • Goddard	Teachers effectively use appropriate methods for project goals		• Improved teaching efficacy • Continually improvement of methods
	Student development • Project-based learning • Problem-based learning • Newtonian physics, rocket stability, fluid dynamics, aerodynamics •	Students are productively engaged in problem-solving projects Students generate data-supported theories about the behavior of their final products	• Build rockets • Heightened interest (attitudes and dispositions) toward STEM • Improved teamwork skills • Improved physics and aerodynamics comprehension • Demonstrate ability to use failure and success as part of continual improvement cycle	• Majors in STEM • College graduates in STEM • Alumni career satisfaction
	External Context: increased interest in STEM and a better prepared STEM workforce			

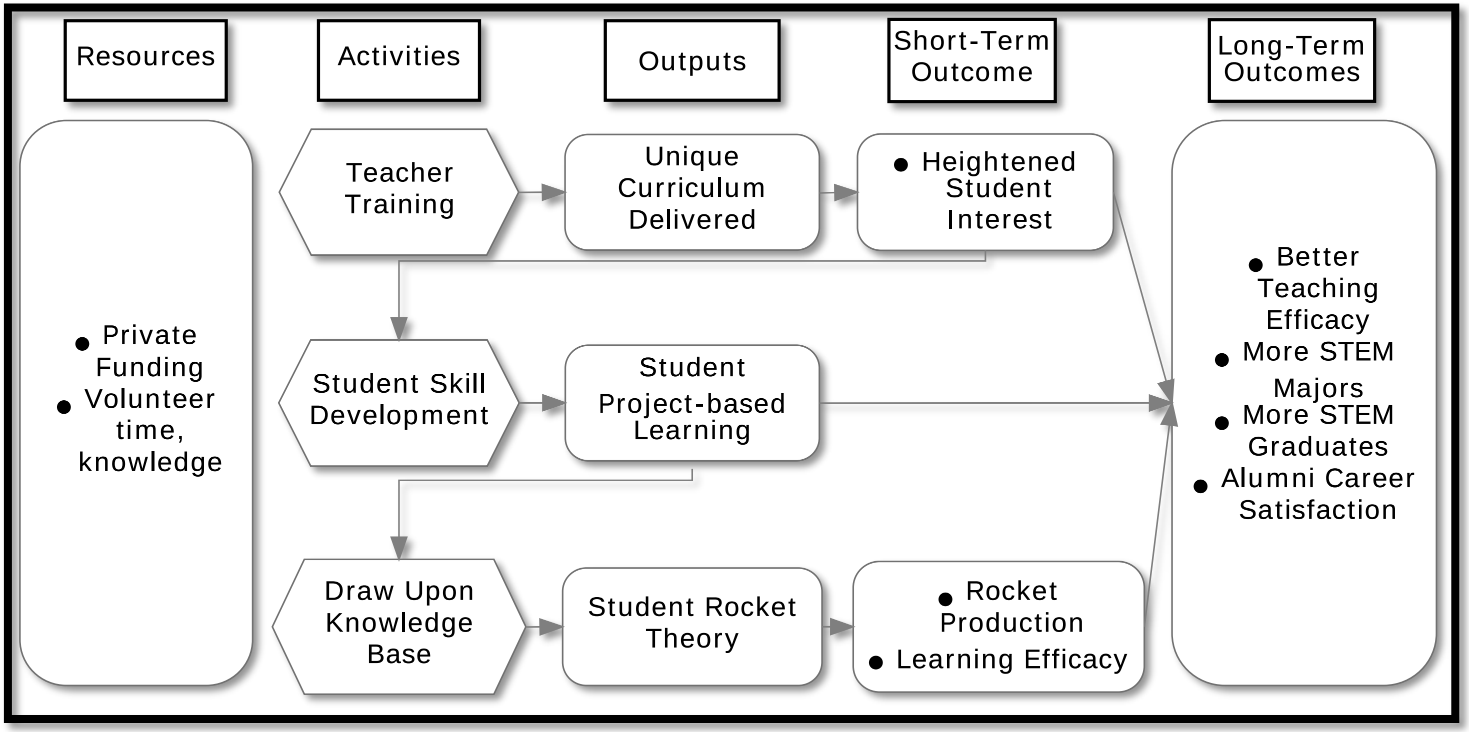

Figure 1. Logic Model for SystemsGo program

The users of the evaluation include SystemsGo staff and private funders. SystemsGo staff will use data as part of its continual improvement cycle. Principally, they will focus on the impact their program makes on students. SystemsGo's funders will use the evaluation for evidence that their investment produced the desired effect. An indirect stakeholder is the SystemsGo evaluation team, which is interested in a deep understanding of why the program works and the continued improvement of evaluation products. Roles for key stakeholders are outline in Table 2.

Table 2. Stakeholder Needs and Uses

Users	Need to Know	Uses
SystemsGo	• What is the impact of program on students? • Determine whether teacher or student curriculum needs revision and where	• Implement program changes to increase effectiveness • Identify data for marketing and expansion campaigns
External Funders	• Determine impact of STEM training • Determine impact of career selection	• Determine whether to fund program • Justify expense • Identify data for marketing campaigns
SystemsGo Evaluation Team	• Determine the effectiveness team performance • Identify factors related to program success	• Determine whether graduate students can perform under real world conditions. • Use success factors in professional educator training

Table 3 outlines the starting questions that were presented to the rocket program's stakeholders for approval. It was important to explain to them the importance of a mapping the questionnaire items to a theoretical frame that is consistent with the theories driving the program and parallel to the goals of the program. The lead evaluator recommended general theories of psychology that explain the relationship with self-efficacy and later behavior and goal attainment. These were consistent with the rocket program's primary mission of inspiring youth to pursue STEM careers. The overarching theories driving the design of questionnaires and interview protocols derive from Bandura's[9,10] theories of social cognition and self-efficacy and those of Lent, Brown, and Hackett's Social Cognitive Career Theory (SCCT)[11]. The Theory of Planned Behavior by Ajzen's[12] was used as a guide for actual item construction and for understanding the relationship among specific attitudinal and self-efficacy constructs that lead to behavioral intentions and change.

Table 3. Starting Items for Pretest/Posttest Questionnaire	
	Based on your experience with SystemsGo,
	Academic performance, persistence, career options.
Self-efficacy	1. How much confidence do you have in excelling in a STEM career? (semantic differential) 2. How much control do you believe you have when it comes to selecting a STEM career? (semantic differential) 3. It's mostly up to me to choose a STEM career 4. For me to become an engineer is entirely possible 5. I can control whether or not our rocket reaches its goal 6. I can figure out complex problems. 7. If the rocket did not fly as expected, I am confident I could figure out why.
	Agree/disagree
STEM Outcome Expectations	1. I will earn an attractive salary 2. I will do work that I find satisfying 3. I will build things that have a lasting effect on society
Technical Interests	Reading articles Solving complicated technical problems,
Social supports and barriers	Get encouragement from friends Feel pressure to change interests from family
*Legacy SystemsGo Item	Items selected from questionnaires not based on SCCT
*National Surveys	

*A few questions will be drawn from past SystemsGo questionnaires. This is done to maintain a small continuity between past and future evaluations. Additionally, a few items will be drawn from National Center for Education Statistics (NCES) national dataset questionnaires. This will allow the evaluation to make direct comparisons between SystemsGo participants and student responses in NCES national surveys.

Chief Analysis Tool for the Evaluation: Segmentation Analysis

The chief analysis tool we used for questionnaire analysis was segmentation analysis. This approach supported the development of interview and observational protocols of teachers and program stakeholders. Segmentation analysis is a statistical analysis technique that helps one divide a sample into groups of interest, for the purpose of targeting services to groups that are differ significantly from each other. The groups were based on participant answers to items on the questionnaire. The criterion or dependent variables are those that provide an overall evaluation of the program. All other variables were used as predictors. With the questionnaire used for this evaluation, there were hundreds of possible associations among variables (questionnaire items) that could be examined. This procedure automatically finds the most the most powerful predictors of a variable of interest. It then divides the sample into groups (segments) based on students' responses to the predictor. These groups are statistically significantly different from each other. It then repeats this procedure for each identified segment. This technique produces a graphical representation of the analysis as presented in *Figure 2.* This type of analysis can be particularly helpful when trying to understand highly skewed data, like we have in the evaluation of popular programs. Here respondents were generally extremely positive, so throughout this analysis, even the lower scores are high.

The effect of interest here is interest in attending college, one of three dependent variables. This dependent variable was selected as an example of what was used in the final evaluation. Four hundred fifty-four (454) participants in the SystemsGo program responded to their level of interest in attending college (see *Figure 2*). Their responses indicated that students were very positive about this choice. On a 100-point scale, the students' mean score was 90.6. Of the various variables in the questionnaire, the best predictor was participants' level of confidence in solving complex problems, at the end of the program. The analysis split this predictor into two groups. Node 2 consists of 263 (57.9%) participants who reported a confidence score of 76 or greater on a 100-point scale. Their mean response to having an interest in attending college was 96. The 191 (42.1%) participants grouped in node 1 reported a confidence score of 75 or lower on a 100-point scale. However, their mean response to having an interest in attending college was still a high 83.

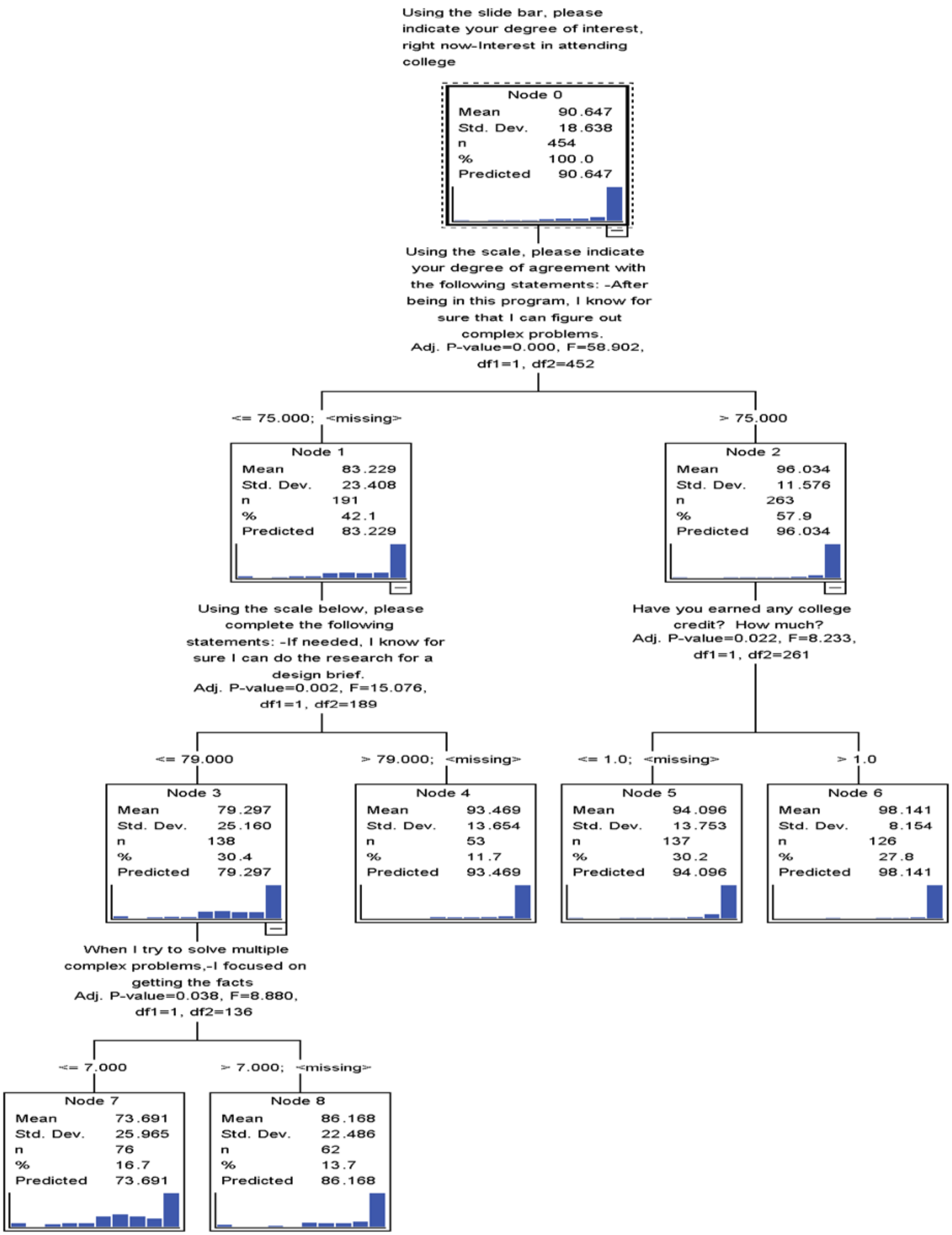

Figure 2. Example Segmentation Analysis

Conclusions

The evaluation used several methods of data collection, with the principal methods being questionnaires, direct observation, self-evaluation, and interviews. Analysis techniques included segmentation and textual analyses. Beginning of year and end of year questionnaires were used to assess student pretest/posttest statues via the Internet. With the help of SystemsGo leadership, schools at each program level (Tsiolkovsky[transonic flight], Oberth, and Goddard [1 pound payload, one mile high]) were purposefully selected for the gathering of direct observation and interview data collection. Observers used field notes as the primary data collection tool. Video and tape recording was used as appropriate and where permissions were not needed. The evaluation team triangulated these data with legacy data in order to complete a series of evaluations that showed students growth while being involved with the program.

Following the final report, select evaluation team members and SystemsGo staff met to review and interpret the findings. The findings were compared to established benchmarks, both internal and national. Not only were stakeholders pleased with the findings, they were pleased with the detailed and transparent manner the evaluation process was handled. The stakeholders approved the public reporting and dissemination of findings by the evaluation team.

In reflecting on this process, it is clear that it is critical that the evaluators and stakeholders worked as a team. The guiding principle for the evaluation team was providing good data that will help the program improve. The guiding attitude was to collect and provide these data, but do so unobtrusively. It has been critical that the evaluation team *not* present as overhead to the program directors and participants. These two ideas (we want you to improve and being unobtrusive) started the conversation with rocket project directors and teachers. It seems to have removed fear, so much so, that teachers would actually seek out the evaluators say this often repeated phrase, “Come over here, we need to show you something.” This full cooperation meant that classrooms and learning setting were open to members of the team, including observing one high school team work into the early morning, preparing their rocket for the next day’s flight. These principles help support communication and coordination between Rocket Project team members and the evaluators. With good cooperation and communication, morale was high for all involved. Though this program is exceptional and reports have be extraordinarily positive, the early development of a good relationship made it easy for the program stakeholders to hear, accept, and act upon any negative reports.

It has often been said that if a person could time travel to a school classroom in the late 19th Century, it would be indistinguishable from most early 21st Century classrooms—even while so many other aspects of life have changed. One cannot say this about SystemsGo’s Rocket Program. Nor can this be said about the evaluation strategies used. Using the team approach, rather than a high stakes and distant evaluation stance, this program can document its success and improve. From the standpoint of the evaluator, several pleasant additional outcomes have resulted:

- The project directors have turned over the entire web-based tracking system over to the lead evaluator.
- Respect among stakeholders, participants, and evaluators has increased morale for all. This has the effect of increasing momentum—communication and cooperation--whenever a job needs to be done.
- Informal interactions have proved to increase accountability among all involved.

- Other STEM groups want to work with the lead evaluator.

Note

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