Abstract

Science, Technology, Engineering, and Mathematics (STEM) outreach programs are becoming increasingly popular and widespread, providing the necessary opportunity to engage K-12 students in these fields. However, it is unclear what the best measures of effectiveness are for these types of programs. It is known that behavioral, academic, and changes in career-related choices can be observed among STEM program participants but limited objective evidence exists to support the goodness of any single measure.

Moreover, the reliability of the data sources, namely the youth, parent, teacher, or administrative records that provide key information about the program experience is unknown. There are also short-term (e.g., improved grades, improved self-confidence) and long-term (e.g., removal of barriers to advancement in math and science) outcomes which present even more difficulties in determining the ideal measures of success.

This paper explores these issues in the context of a STEM outreach program called the Arizona Science of Baseball, managed by the University of Arizona, employing systems engineering principles. Participants in a 2012 pilot program were 7th and 8th grade students from Mansfield Middle School in Tucson, Arizona which provide a useful case for testing and evaluating a variety of measures.

© 2013 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-ND license.
Selection and/or peer-review under responsibility of Georgia Institute of Technology

Keywords: STEM; Outreach Programs; System Engineering Principles; Science of Baseball; Effectiveness Measures; Outcomes

1. Background

In order to address the shortage of engineers and scientists in the U.S. numerous opportunities are being created to expose students to these subjects during primary and secondary education. One such program at the University of Arizona is aimed at promoting Science, Technology, Engineering, and Mathematics (STEM) program through the
sport of baseball. It is called the Arizona Science of Baseball (ASB) and emphasizes the Arizona common core standards in mathematics. The overall goal is to translate the love of baseball into an appreciation, understanding, and passion for the underlying science and mathematics and thus have an impact on the excessively small percentage of students that complete a 4-year degree in a STEM field (See Fig. 1. STEM Pipeline). Our underlying hypothesis is that by making a connection between physical activities such as baseball and STEM topics we can empower students who are underperforming academically by focusing on their athletic interests, capabilities, and strengths. Outcomes of interest also include the pursuit of better life choices, such as the importance of regular physical activity, healthy eating, and lifelong learning. In the process of improving academic achievement and providing a path to college, our program has the potential to elevate socioeconomic status.

The aim of this paper is to describe the program and its objectives, how it builds on the previously implemented programs, present the metrics used for evaluation, and discuss the initial validation work completed in conjunction with a pilot program implementation.

Fig. 1. STEM Pipeline

2. Science and Baseball

The learning modules for the Arizona Science of Baseball program build upon materials from the MIT Science of Baseball [1] and Cal Ripken, Sr. Foundation (http://www.ripkenfoundation.org/). Specific topics covered in biology, mathematics, and physics are listed below (See Table 1. Arizona Science of Baseball Topics). These support STEM initiatives directly by focusing on the National Science Education Standards defined by the National Academy of Science [2]. With one exception, the Science Content Standards covered by the proposed program are:

1. Unifying concepts and processes in science
2. Science as inquiry
3. Physical science
4. Life science
5. Earth and space science (not covered)
6. Science and technology
7. Science in personal and social perspectives
8. History and nature of science

With one or more Science Content Standards in mind, each baseball topic is comprised of two components: academic and athletic. For example, students learn about geometric angles on the baseball field through an
explanation of fundamental concepts (i.e., right angles, parallel and perpendicular lines, proportions, etc.) via a classroom presentation following the “Science as inquiry” standard. Next, the application of the concepts will help them internalize the ideas through the measurement of an actual baseball field and doing drills to verify distances and speed between key playing areas. This mixed mode of instruction promotes student engagement and addresses specific learning styles in each cohort (i.e., visual, auditory, read/write, and kinaesthetic).

Table 1. Arizona Science of Baseball Topics

<table>
<thead>
<tr>
<th>Biology</th>
<th>Mathematics</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sports safety</td>
<td>Base running</td>
<td>High altitude baseball</td>
</tr>
<tr>
<td>Reaction time for batters and runners</td>
<td>Geometric angles on the baseball field</td>
<td>Temperature effects on baseball flight</td>
</tr>
<tr>
<td>Heart rate</td>
<td>Home run distances at different ballparks</td>
<td>Bat materials</td>
</tr>
<tr>
<td>Muscle fatigue</td>
<td>Finding the sweet spot of the bat</td>
<td>Swing mechanics</td>
</tr>
<tr>
<td>Nutrition</td>
<td>Selecting the right bat</td>
<td>Hitting a ball in motion</td>
</tr>
<tr>
<td>Stress</td>
<td>Baseball statistics/sabermetrics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Batter/pitcher matchup</td>
<td></td>
</tr>
</tbody>
</table>

Each baseball topic is also used to explore one or more of the following concepts [2]:
- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Evolution and equilibrium
- Form and function

Following the example on geometric angles, “Change, constancy, and measurement” will play a significant part in how the hands-on activity works. The curriculum is designed so that it can be replicated elsewhere.

3. Program Description

The Science of Baseball program is organized, designed and implemented to contain the following features:
- The development of the curriculum for 7th and 8th grade that includes classroom activities (e.g., demonstrations, films, clinics), athletic activities (drills, scrimmages, coaching), and take-home activities (“Baseball to go”). The take-home activities provide an opportunity for the students to teach their siblings, family, and friends about what there are learning.
- Month-long camps for middle school boys and girls that cover topics such as batting averages, muscle fatigue, reaction time, team building, base running, hitting, etc., and the fundamental math/science principles that can be used to understand them.
- Weekend camps for middle school teachers to learn the curriculum from faculty and staff at the University of Arizona enabling them to take it back to their schools. We estimate that each teacher will be able to disseminate the Science of Baseball program to 125 students over an academic year and therefore impact thousands of kids.
- An on-going mentorship program that will have a lasting impact on the students after they complete the Arizona Science of Baseball program. This also enables the establishment of a network of support for students, parents, and teachers.

Initially, the program’s target population is middle school students and teachers from under-performing schools in Arizona [3,4] although there are plans for expansion to other locations. With this curriculum in mind, the question still remains: how do we measure the impact of the program? The remainder of the paper addresses this topic.
4. Measure of Effectiveness

The specific measures of effectiveness (metrics) for the Arizona Science of Baseball are motivated by the following four objectives:

4.1 Increase Student Awareness of STEM as an Educational/Career Option.

America’s favorite pastime has been shown to be an effective subject to expose children to math and science as evidenced by the successful MIT Science of Baseball Program in Boston. In this same spirit, the Arizona program will give students the ability to learn basic academic concepts through hands-on application on the field. We strive to not only expose students to STEM fields, but to help them understand, visualize, and integrate the connection between baseball, science, and mathematics through a variety of learning styles (i.e., visual, kinesthetic, auditory). These hands-on experiences will encourage continued involvement and enrollment in math and science classes that will promote academic and career pursuits in related fields.

4.2 Motivate Students to Excel Despite Obstacles.

In addition to the academic objectives of the program, a parallel objective is to motivate students to excel despite social, economic, and cultural obstacles (either real or imaginary) that may prevent them from advancing their education. The Arizona Science of Baseball program will include motivational “pep talks” by invited guests such as Rick Ramirez (Head Coach of the 2009 Little League World Series Champions), Andy Lopez (Head Coach of the University of Arizona’s 2012 College World Series Champions), and Martin Martinez (CEO of ESA Corporation and designer of Louisville Slugger aluminum bat). Each of these individuals has a compelling story to tell about overcoming adversity that provide real-world encouragement that students should pursue their dreams.

4.3 Provide a Measurable Opportunity for Individual Transformation.

We strive to provide a life-changing transformative experience for at-risk kids from academically underperforming schools in Arizona. Many of the targeted students could be the first in their family to pursue a college education. This provides an opportunity to inspire an educational path that might be unimaginable or perceived as impossible. Our objective is to also measure the impact of the program on students’ academic performance and life choices. This will be accomplished by assessing each student’s math & science levels at the beginning of the program, at the end of the program, and six months after the program. We will also interview the students, their teachers, and their families to determine other intangible impacts that resulted from their participation in the program.

4.4 Establish a Framework for Sustainable Change.

In order to reinforce the lessons learned at the Arizona Science of Baseball program and maximize the likelihood for improved academic achievement, each participant will be assigned a mentor. The mentor will engage the student in dialog about academic and personal achievement facilitated through participation in reunion games held once per quarter. Mentors will be recruited from the University of Arizona Science and Engineering colleges, the Society of Hispanic Professional Engineers UA student chapter, University of Arizona Baseball Club team, the Arizona Assurance program, and University of Arizona Honors College. Furthermore, we will establish partnerships with math & science teachers at local middle schools to reinforce the lessons learned from the program and invite parents to attend information sessions, games, and awards ceremonies with the intent to educate them and gain their support in their children’s involvement in the program.

An assessment plan has been developed that identifies the specific measure (metric), the method of measurement, the frequency of collection, and the comparison group (See Table 2 Assessment Plan). The assessment plan will also serve as a backbone to identify areas of improvement for the program. In summary these measures are divided into two groups: short to mid-term indicators and long term indicators. A summary of these are provided below:

4.5. Short Term / Mid-Term Measures

The program will utilize short math tests, attendance, and performance on standardized math testing as short term and mid-term measures. Participants will take a short math quiz before each program session begins (Pre-test) and
one towards the end of that same session (Post Test) at the same level of difficulty. The results of the two quizzes will indicate the impact the program had on participants on their mathematics knowledge. Based on the feedback received from thirty teachers, representing several Arizona middle schools and high schools, as well as representatives of the Arizona Department of Education attendance and instances of discipline will be the metrics linked to measuring the program’s impact on the participants’ attitude towards school. A comparison between the participants’ attendance and discipline data before and after participation in a program will be utilized to measure a change in the participants’ attitude towards STEM and school. The participants’ attendance and discipline results will be compared with both, previous program participants, and similar grade level students from their respective school. Evaluation results are going to indicate the program’s impact regarding these issues. Additionally, each quarter the ASB program researchers will collect standardized mathematics testing results. This information will reflect the effectiveness the program had on participants’ performance in a STEM topic.

4.6. Long Term Measures

The program will utilize a mentorship program, graduation rate, matriculation rate in tertiary education and completion of a STEM degree as long term measures. The mentorship program will allow the collection of more comprehensive data from participants and will be vital in measuring the program’s long term effectiveness. The detailed implementation of these measures is in a developmental phase, but the general tenets are described here. The mentorship program will be quantified with the use of interviews and surveys 6, 9, and 12 months after the completion of the program. The program intends to establish a “stretch” relationship with participants’ parents and teachers to further enhance the success of the mentorship program. High school graduation rates and university enrollment rates will be used as indicators of long-term impact. This information will be acquired either from the participants themselves or from school district records. Finally, the last statistic that the program plans to collect from participants is the selection and completion of a STEM degree at the bachelor’s level.

Table 2. Assessment Plan

<table>
<thead>
<tr>
<th>Measure</th>
<th>Instrument/Method</th>
<th>Frequency</th>
<th>Comparison group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math competencies</td>
<td>5-question math quiz based on common core standards</td>
<td>Before program begins</td>
<td>Self</td>
</tr>
<tr>
<td>Attendance in school</td>
<td>Data from school</td>
<td>Weekly</td>
<td>Other Mansfeld students</td>
</tr>
<tr>
<td>Discipline</td>
<td>Data from school</td>
<td>Weekly</td>
<td>Other Mansfeld students</td>
</tr>
<tr>
<td>Math scores on standardized test</td>
<td>Data from school</td>
<td>Quarterly</td>
<td>Other Mansfeld students</td>
</tr>
<tr>
<td>Attitudes towards STEM</td>
<td>Math Personality Profile</td>
<td>Week 1 and week 6</td>
<td>Self</td>
</tr>
<tr>
<td>Effectiveness of mentorship program</td>
<td>Interviews/surveys</td>
<td>6, 9, 12 months after the program</td>
<td>Other STEM programs</td>
</tr>
<tr>
<td>Graduation rate</td>
<td>Data from school</td>
<td>Upon completion of High School</td>
<td>Other Mansfeld students</td>
</tr>
<tr>
<td>Rate of matriculation to tertiary education</td>
<td>Data from individuals</td>
<td>Upon enrollment in Community College or University</td>
<td>Other Mansfeld students</td>
</tr>
<tr>
<td>Selection and completion of STEM degree</td>
<td>Data from individuals</td>
<td>Upon graduation from University</td>
<td>Other Mansfeld students</td>
</tr>
</tbody>
</table>

5. Initial Validation

A workshop was held in September, 2012 at the University of Arizona where thirty teachers, representing several Arizona Middle Schools and High Schools, as well as representatives of the Arizona Department of Education were in attendance. The purpose of the workshop was to present the Arizona Science of Baseball program, with the
specific intent to receive feedback on the validity of the planned program and the metrics to be utilized to measure the program’s effectiveness.

The event featured Dr. Lynne M. Borden, Thomas W. Warne Professor of Excellence in Youth Development, and Dr. Ricardo Valerdi, Associate Professor from the Systems and Industrial Engineering department. Dr. Borden provided a review of the University as a resource to Arizona educators and administrators in developing and implementing middle school and high school after-hours programs. Dr. Ricardo Valerdi, Arizona Science of Baseball Coordinator, continued with a review of the lack of future students in STEM fields. A case was made for the needs of engineers to contribute to society and the lack of STEM field trained professionals available to address such needs. The Arizona Science of Baseball program was introduced as a means producing a meaningful impact on middle school students studying STEM fields.

In addition, Dr. Ricardo Valerdi orchestrated a small demonstration of an activity (catching cards vs. catching cards of a specific color) in which probabilistic concepts were combined with human reaction times. This activity was done to demonstrate the type of activities employing physical, physiological, and psychological human capabilities (senses, kinematics, information processing, and decision making) with STEM academic content. As was evidenced by the audience response, enthusiasm was quickly fostered during the activity and a realization of direct applicability with middle school students was apparent.

Group discussions were facilitated to generate feedback that would allow the organizers to improve the curricula for the program and refine the content offered with respect to the content to be covered by the Arizona Science of Baseball Program. The key area of interest for ASBP coordinators was to have the proposed assessment plan and its metrics evaluated against the conference attendees’ experiential expertise. They were able to provide valuable feedback, in confirming that our assessment plan provided the capability of measuring short to mid-term and long term impacts.

Additionally, they were able to provide these specific insights:

- Making performance assessments fun for students while making them effective and objective enough to participate in studies. Suggestions regarding how to involve students in learning processes and the importance of building a connection between the theory offered by the program and real-world applications was provided.
- According to the teachers that attended to the meeting, students might begin reflecting interest and confidence in math and science within the first five weeks of the program by becoming math “leaders” within their groups.
- As a request everyone suggested that, if the obtained data reflect the impact of the program is available, the program should be implemented in various schools to improve the level confidence of the students with respect to science, technology, engineering and math subjects. Schools would like to have a teacher’s manual with step-by-step instructions on how to replicate the Arizona Science of Baseball program in an efficient and effective manner.
- The discussion session offered positive reactions and good critiques about the emergent program. Representatives from the Arizona Department of Education and from local schools expressed excitement for how the curricula could potentially influence participating students.
- The majority, if not all of the school correspondents, were interested in being part of this program. Some of the teachers were interested in starting a baseball league where attendance to after-school-time lectures involving STEM topics would be required. This would allow schools to invest their grants for scholar improvement levels in a way where physical education and STEM education is promoted.

6. Pilot Program Results & Validation

6.1 Pre-Tests and Post Tests

The pre-tests and post tests of the pilot program implemented in October and November 2012 are being utilized as leading indicators of the potential impact the Arizona Science of Baseball program will have. These tests provide immediate feedback about the effectiveness of the program in its earliest stage. All pre-tests and post-tests consisted on one or two multiple choice questions of the same level of difficulty. Different techniques were used to test
participants. For instance, in Week 4 participants completed a more traditional written test while in Week 5 computer answer collection software “clickers” were used to gather and tabulate answers.

The results indicate that the program had a positive impact on the 58 participants tested (See Fig. 2. Summary of Results for Pre-tests and Post Tests and Table 3. Summary of Results for Pre-tests and Post Tests). All the testing averages showed improvement except the tests on Week 5. The pre-test questions on Week 5 were not at the same level of difficulty as compared to the post test. The overall four week pre-test average was 75% and the overall four week post-test average was 86%.

![Summary Pre-tests and Post Tests](image)

**Fig. 2. Summary of Results for Pre-tests and Post Tests (No. Respondents Wk3 = 14, Wk4 = 15, Wk5 = 11, Wk6 = 18)**

**Table 3. Summary of Results for Pre-tests and Post Tests (No. Respondents Wk3 = 14, Wk4 = 15, Wk5 = 11, Wk6 = 18)**

<table>
<thead>
<tr>
<th>Summary of Results</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>Average Pre-test Score</td>
<td>Average Post-test Score</td>
</tr>
<tr>
<td>3</td>
<td>71%</td>
<td>81%</td>
</tr>
<tr>
<td>4</td>
<td>70%</td>
<td>92%</td>
</tr>
<tr>
<td>5</td>
<td>78%</td>
<td>73%</td>
</tr>
<tr>
<td>6</td>
<td>82%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>75%</strong></td>
<td><strong>86%</strong></td>
</tr>
</tbody>
</table>

6.2 Mid-term Measures

The mid-term measures that are being utilized as a result of the pilot program are STEM/school attitude, standardized testing results and math course grades. Each of these metrics is described below along with the accompanying results.

6.2.1 Attendance

One of the assumptions made for the attendance measure is that the participant’s official school attendance as an indicator of interest towards their courses. This measure aims to identify a relationship between participation in the Arizona Science of Baseball pilot program and increased attendance and success in school, particularly STEM related courses. This link was substantiated by teachers, representing several Arizona middle schools and high schools, as well as representatives from the Arizona Department of Education.

Data regarding the participant’s (thirteen students) first three months of school attendance was collected and further data for the next three months will be collected (See Fig. 3, Participant’s Attendance Data, Fall 2012). The purpose is to compare these data sets and identify a possible change of attendance levels that serve as an indicator or measure in the change of attitude towards STEM related courses.
6.2.2 Standard Test Performance

The Arizona’s Instrument to Measure Standards (AIMS) indicates student proficiency of the Arizona Academic Content Standards in fields such as writing, reading, mathematics, and science. AIMS is a standardized test that middle schools are required to administer by Federal and State law.

This project will be using AIMS to measure participant’s performance in mathematics. Data provided by Mansfeld Middle School includes the participant’s (thirteen students) performance scores in the 2012 test (See Fig. 4. Participants’ Performance on AIMS, Mathematics Scores 2012). As a mid-term measurement, the scores obtained will be compared with data that will be obtained for AIMS Test in 2013. The purpose of this measurement is to identify the possible influence that the Arizona Science of Baseball pilot program might have on the participants’ performance in a mathematics standardized test.
6.2.3 Grade Performance

Grades of the participants (thirteen students) will also be considered as a measure of performance. The aim is to detect a change in the participants' grade performance specifically in their respective mathematics course(s). Data that includes grades for the term of Fall 2012 was provided by Mansfeld Middle school will be used as the baseline (See Fig. 5. Participant's Mathematics Course(s) Letter Grade Performance Fall 2012). We intend to compare this baseline data with grade results from the next set of grading periods and compare these to their peers.

![Fall Term Letter Grades](image)

Fig. 5. Participant's Mathematics Course(s) Letter Grade Performance Fall 2012 (No. of Participants = 13)

7. Conclusion

The Arizona Science of Baseball is a program under development, but its first pilot implementation conducted in October-November 2012, shows considerable promise. Based on the evaluation of the initial results, the Arizona Science of Baseball has the potential to significantly impact the academic trajectory of many students in the state of Arizona. The program coordinators and supporters have concluded that there is enough initial evidence to proceed with further program and curricula development along with marketing and branding efforts to secure funding to implement the program on a larger scale.

Acknowledgements

We appreciate the support of the Cindy Trejo of the Arizona Department of Education, Professor Lynne Borden and her staff, Principal Paul De Weerdt of Mansfeld Middle School, and Tucson Unified School District for allowing us to perform this research.

References