The Journal of Primary Prevention (2020) 41:71–85
https://doi.org/10.1007/s10935-020-00577-1

ORIGINAL PAPER

Minimizing Health-Compromising Behaviors via School-Based Programs: An Optimization Approach

Niloofar Bavarian[1] · Banafsheh Behzad[2] · Sheena Cruz[1]

Published online: 9 January 2020

Abstract
School health programs are united by their desire to promote health and health-related outcomes among youth. They are also united by the fact that their expected effects are contingent on successful program implementation, which is often impeded by a multitude of real-world barriers. Techniques used in management science may help optimize school-based programs by accounting for implementation barriers. In this exploratory study, we present a detailed example of the first known application of linear programming (LP), which is an optimization technique, to *Positive Action* (*PA*). *PA* is a social emotional and character development program that includes a six-unit, teacher-delivered, classroom curriculum. We specify how we used LP to calculate the optimal levels of program implementation needed to minimize substance use, subject to known levels of implementation barriers (e.g., disruptive behavior, teacher education, teacher attitudes towards character development, school resources, and school safety). We found that LP is a technique that can be applied to data from a school health program. Specifically, we were able to develop a model that calculated the number of lessons that should be taught to minimize a specific health-compromising behavior, given expected levels of predetermined implementation barriers. Our findings from this exploratory study support the utility of applying LP during the program planning and implementation processes of school health programs.

Keywords Linear programming · School programs · Program planning · Character education

✉ Niloofar Bavarian
Niloofar.Bavarian@csulb.edu

Banafsheh Behzad
Banafsheh.Behzad@csulb.edu

[1] College of Health and Human Services, California State University, Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840, USA

[2] College of Business Administration, California State University, Long Beach, Long Beach, CA, USA

Introduction

School-based health-promotion programs come in various forms (e.g., social skills training, behavior modification, mentoring) and have a variety of aims (e.g., reduced substance use, improved emotional development). What unites these programs is that their attainment of desired outcomes is often directly associated with implementation levels (Durlak & DuPre, 2008). One indicator of implementation, which broadly refers to program delivery, is dosage, which refers to the quantity of program delivery (Dane & Schneider, 1998). Implementation intensity, which includes dosage, can be influenced by a multitude of factors (Payne, Gottfredson, & Gottfredson, 2006), and accounting for these during the program planning stage for school-based programs may facilitate the attainment of desired outcomes.

Implementation is influenced by factors that can occur at various levels (e.g., teacher, school, student; Domitrovich, Gest, Gill, Jones, & DeRousie, 2009; Pas, Waasdorp, & Bradshaw, 2015). For example, provider characteristics, including whether teachers have the required skills (e.g., education level) and experience to deliver the program, and their attitudes towards the program, all influence implementation (Beets et al., 2008; Linnell et al., 2016; Wang et al., 2017). Barriers to implementation can also occur at the student level, and include issues related to behavioral disruptions and discipline (Botvin, 2004; Pas et al., 2015). At the school level, safety can influence implementation levels both directly and via its impact on classroom engagement (Cote-Lussier & Fitzpatrick, 2016; Pas et al., 2015). Characteristics of the organizational climate (e.g., school climate) can also influence implementation (Beets et al., 2008; Malloy et al., 2015). Specifically, schools with higher levels of resources (e.g., funds, materials, equipment) have been shown to achieve higher levels of implementation (Domitrovich et al., 2009). Thus, it is apparent that school-based efforts to maximize health-promoting outcomes and minimize health-compromising outcomes must take into account anticipated levels of such factors in order to calculate the minimum levels of implementation needed to achieve desired results. Optimization is an approach that allows for such resource allocation to take place.

Linear programming (LP) is an optimization technique which uses a mathematical model of linear equations with the objective of planning the best possible allocation of scarce resources, under a set of constraints that serve as barriers to implementation (Massachusetts Institute of Technology, 1977). LP has three main components: an objective function, decision variables, and constraints. In the context of school-based programs, these represent the outcome of interest, implementation indicators, and barriers to implementation, respectively. The objective function/outcome of interest is a linear function of the decision variables subject to constraints (which are also linear functions of the decision variables). One advantage of this technique is that it allows for known or anticipated values of scarce resources to be incorporated into the model (Silver, Pyke, & Peterson, 1998), and is used to calculate the optimal way to allocate these limited resources (Hillier & Lieberman, 2005); this feature can be particularly helpful in settings where resources are limited and competing demands for resources exist (e.g., such as school-based programs implemented in low-income settings).

Although the LP technique is rooted in the disciplines of management science, there are a growing number of examples of its use in health care research (e.g., Earnshaw, Hicks, Richter, & Honeycutt, 2007; Flessa, 2000; Kuo, Schroeder, Mahaffey, & Bollinger, 2003; Mulholland, Abrahamse, & Bahl, 2005; Tianviwat, Chongsuvivatwong, & Birch, 2009). In addition, there is an emerging trend towards behavioral intervention research using engineering- and resource management-rooted techniques to optimize and evaluate interventions (Collins, Kugler, & Gwadz, 2015). To date, however, the application of the LP technique to school-based programs has been limited, even though program implementation is related to time allocation directly and, thus, to resource allocation indirectly. As such, it is possible that application of LP to school-based programs could facilitate an understanding of implementation levels needed to optimize desired outcomes.

The purpose of our exploratory study was to apply LP to one specific, school-based program, *Positive Action* (*PA*). *PA* is a social emotional and character development (SECD) program in which lessons are delivered by the classroom teacher. From 2004 to 2010, *PA* was implemented via a randomized controlled trial in seven Chicago Public Schools in low-income settings. Our outcome of interest (i.e., the objective function) in this exploratory study was substance use, a health-compromising behavior. Our goal was to employ LP to determine if it might be possible to obtain estimates of the specific amounts of implementation needed (i.e., number of weekly lessons for each of the units needed to be taught: the decision variables) to minimize a health-compromising behavior (i.e., substance use: the objective function), given pre-specified and expected levels of various implementation barriers (i.e., the constraints).

Methods

Data Source

The school-based (clustered), randomized controlled trial of *PA* set in Chicago was a longitudinal study conducted from 2004 to 2010. During the trial, a dynamic cohort of students was followed from grades 3–8. The study was approved by the Chicago Public Schools Research Review Board, as well as the respective entities of each participating university. Fourteen diverse low performing and high poverty schools were matched into seven pairs, and schools within each pair were randomized to treatment (receipt of the *PA* program) or control (business as usual). For our exploratory study examining the feasibility of LP, we used data from treatment schools during the last 2 years of the study.

To date, results from the Chicago trial of *PA* have shown an impact on substance use (Lewis et al., 2012) among *PA* versus control students, and have demonstrated that the implementation of the program curriculum varied across *PA* schools (Malloy et al., 2015). Implementation data also showed that teachers from grades 7 and 8 reported teaching lessons from all six units in their respective academic years, which deviates from the intended curriculum design (discussed below); one possible explanation for this action is that the funding timeline prevented *PA* from being implemented in grade 6. As such, we proceeded with analyzing the data using the LP technique as the program was *actually* implemented, rather than how it was designed to be implemented.

The PA Curriculum

The six units of the *PA* curriculum focus on the following content: self-concept, Positive Actions for the body and mind (including refraining from substance use), self-management, prosocial interactions, self-honesty, and self-improvement. The number of lessons in the six-unit *PA* curriculum, which is delivered by teachers during classroom time, is approximately equal across the units; when delivered as intended, the maximum number of lessons per unit ranges from 24 (Units 2 and 4) to 31 (Unit 3). For each of grades 7 and 8, 20-min interactive lessons per grade are supposed to be taught twice a week; grade 7′s 82 lessons should focus on Units 1–3 and grade 8′s 83 lessons should focus on Units 4–6. As mentioned above, however, during the Chicago trial, all six units were taught during grade 7, and we proceeded with our analyses accordingly.

Study Participants

We utilized data from treatment schools only. We applied the linear program to minimize substance use at wave 8 (i.e., the spring of grade 8). At wave 8, we had 218 students in *PA* schools. Of these students, 61.5% identified as girls; and 55.2% identified as African American, 29.0% as Latinx, 8.7% as White, and 7.1% as Other.

Instrumentation, Procedure, and Data Analysis

We combine descriptions of the measures, procedures, and the analytic plan (including equations) to elucidate how we used LP to calculate the optimal levels of program implementation (i.e., the decision variables) needed to minimize substance use (i.e., the objective function), subject to known levels of implementation barriers (i.e., the constraints). The three main components of the LP model used in this study were the decision variables, objective function, and constraints.

Decision Variables

The decision variables reflected lesson delivery by unit (e.g., Unit 1: Self-concept to Unit 6: Self-improvement). At the end of the grade 7 academic year (Fall 2008-Spring 2009), *PA* teachers ($n=50$; ~70% female) completed an implementation survey. Implementation surveys were completed by the teachers who actually delivered the program (i.e., homeroom teachers). Six items (one item per each of the six units) on the survey asked the teacher, “On the average week during Unit i (i = 1…6), how many lessons did you teach?” Response options ranged from “0” to “5 or more.” Each of these six variables had a normal distribution.

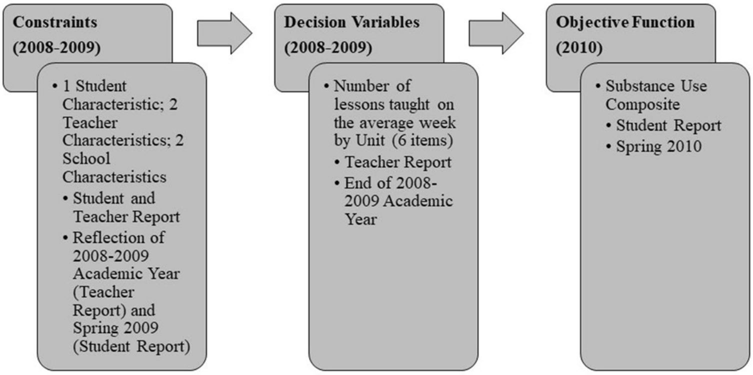

Fig. 1 This figure shows the temporal flow for the information which contributed to the constraints, decision variables, and objective function

Objective Function

The objective function (i.e., outcome of interest) was substance use (*SU*) at wave 8. We used this time point as the objective function to better establish a temporal relationship with the decision variables. We measured substance use using an adapted version of the CDC's Risk Behavior Survey (Centers for Disease Control & Prevention, 2016). The five-item composite (which we created as an average of five items to stay consistent with past studies) asked students (i.e., grade 8 *PA* students, $n=218$) to report their experience with cigarettes, alcohol, marijuana, and other drugs. The response items were based on frequency of use, where 1 = no use, 2 = once, 3 = 2 to 5 times, and 4 = more than 5 times. Program effects on SU at the end of grade 8 were previously reported (Lewis et al., 2012); we focused this exploratory study on determining the feasibility of using LP to calculate optimal levels of lesson implementation needed per unit during the 2008–2009 academic year to minimize substance use (a health-compromising behavior) during the 2009–2010 academic year, subject to constraints present during the 2008–2009 academic year; again, we took this this approach to better establish temporality (see Fig. 1). Therefore, our objective function represents a minimization problem.

Constraints

In the context of a school-based program, constraints represent factors that could hinder implementation. In this exploratory study, we considered the following constraints, all of which were reported by all *PA* teachers during the 2008–2009 (grade 7) academic year ($n=42$ teachers): one student-related constraint was reported (disruptive behavior); two teacher-related constraints were reported (level of education, perceived responsibility to teach SECD); and two school-related constraints were reported (adequate resources, safety).

Analytic Steps

Developing and solving the optimization model, with the objective of minimizing substance use, required a series of steps. We first created one merged dataset that combined students' reports of substance use at the end of grade 8, that is, spring 2010 (for the objective functions); 2008–2009 teacher report of *PA* curriculum implementation (for the decision variables); and teacher reports from all *PA* school teachers that reflected different school context indicators during 2008–2009 (for the constraints).

We derived the objective function coefficients and the constraints using simple regression analyses. We estimated (using Stata v14) six simple regressions; in each regression, substance use (*SU*) at wave 8 served as the dependent variable, and the number of lessons during Unit i (i = 1…6) at wave 7 served as the independent variable. We chose to estimate six simple regressions rather than one multiple regression with all six units (and potential covariates such as prior substance use) as we were interested in observing the individual effect of each unit's lesson delivery. Additionally, although students were nested within schools, the intraclass correlation by schools for substance use at wave 8 was 0.04; this further supported our use of a simple (as opposed to hierarchical) model. Given the skewed nature of the dependent variable, Stata's 'tobit' command was used for the analyses. Let $u_1, \dots, u_6$ represent the decision variables (i.e., "On the average week during Unit i, how many lessons did you teach?"). The six regression equations yield the following objective function:

$$Min \quad -0.123u_1 - 0.128u_2 - 0.138u_3 - 0.152u_4 - 0.152u_5 - 0.152u_6 \tag{1}$$

The coefficients of the decision variables in the above equation come from the coefficients of $u_1, \dots, u_6$ in the regression equations.[1] The y intercept of the six regression equations are not included as those constants did not have any effect on the optimal decision variables values. Equation (1) minimized substance use as a function of the number of lessons taught during each Unit.

The following constraints, reported by teachers during the grade 7 academic year, were considered for their literature-supported relationship with program implementation. The items were created by the original research team.

[1] Simple linear regression equations used to form the objective function (Eq. 1):

$$SU = -0.123u_1 + 1.141$$

$$SU = -0.128u_2 + 1.145$$

$$SU = -0.138u_3 + 1.175$$

$$SU = -0.152u_4 + 1.214$$

$$SU = -0.152u_5 + 1.214$$

$$SU = -0.152u_6 + 1.214$$

Student Constraints

Teachers rated their level of agreement (1 = Strongly Disagree to 5 = Strongly Agree) with seven items that represent *disruptive behavior of their students*. Sample items included "There are many disruptive, difficult students in the school" and "There are many noisy, badly-behaved students." We reverse coded four of the items, created a composite in which a higher score reflected more disruptive behaviors by students (Cronbach's alpha: 0.91). To form each constraint, we ran a simple linear regression, in which the number of lessons during Unit i (i = 1…6) served as the dependent variable and the teacher report of student disruptive behavior served as the independent variable. We then substituted the actual mean of the student disruptive behavior at wave 7 (2.88) in the simple linear regression equations. Since we expected lower amounts of disruptive behavior to be associated with greater lesson delivery (i.e., an inverse relationship), we developed the equations with student disruptive behavior as being less than or equal to its mean in wave 7. Six constraints[2] were obtained for each Unit 1 through 6. These constraints for Units 1 to 6 were due to student disruptive behavior. Note that we selected all six units because the direction of the slope in the simple linear regression models was in the hypothesized direction. In other words, we expected that disruptive behavior and the number of lessons taught during each week would have an inverse relationship, and therefore expected a negative slope.

Teacher Constraints

Teachers indicated their *level of education*; we recoded this item as binary (0 = Less than a Master's Degree; 1 = Master's Degree and above). To form each constraint, we ran a simple linear regression, in which the number of lessons during Unit i (i = 1, 2, 3, 6) served as the dependent variable and the level of education served as the independent variable. We then substituted the actual proportion of teachers with at least a Master's degree/the "mean" of the level of education at wave 7 (0.76) in the simple linear regression equations. Since we hypothesized that there should be a direct relationship between level of education and implementation, we developed the equations with level of education to be more than or equal to its "mean" in wave 7.

[2] Constrains related to student disruptive behavior: $u_1 \leq 3.356^2$ (obtained from nonequality $^1u_1 \leq 0.7672 \times 2.88 + 1.1462 = 3.356$)

$$u_2 \leq 3.197$$

$$u_3 \leq 3.197$$

$$u_4 \leq 3.213$$

$$u_5 \leq 3.182$$

$$u_6 \leq 3.112$$

We specified four constraints[3] for Units 1, 2, 3, and 6. These Constraints for Units 1, 2, 3, and 6 were due to teacher's various levels of education. Note that we selected Units 1, 2, 3 and 6 because their slopes in the simple linear regression models were as hypothesized.

Teachers rated how often they thought 15 different components of SECD should be taught (e.g., character education; being thoughtful to others; goal setting skills), on a scale of 1 = Never to 5 = Always. We created a composite in which higher scores represented more of a *teacher's perceived responsibility to teach SECD* (Cronbach's alpha: 0.98). To form each constraint, we ran a simple linear regression, in which the number of lessons during Unit i (i = 1, 2, 3) served as the dependent variable and the teacher's responsibility to teach SECD served as the independent variable. We then substituted the actual mean at wave 7 (4.22) in the simple linear regression equations. Since we hypothesized that there should be a direct relationship between teacher's responsibility to teach SECD and lesson delivery, we developed the equations to be more than or equal to its mean in wave 7. We obtained three constraints[4] for Units 1, 2, and 3. These constraints for Units 1 through 3 are due to teachers' perceived responsibility to teach SECD. Note that among the six units, we selected the first three units due to the direction of the slope being in the hypothesized direction in the simple linear regression equations.

School Constraints

For the *adequate resources* variable, teachers used a Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) and stated their agreement with 7 items (e.g., "The school or department library includes an adequate selection of books and resources"; "Adequate duplicating facilities or services are available to teachers"). We reverse coded four items and created a composite score in which higher scores reflected more resources (Cronbach's alpha: 0.52). To form the constraint, we ran a simple linear regression, in which the number of lessons during Unit 1 served as the dependent variable and the adequate resources served as the independent variable. We then substituted the actual mean of the adequate resources composite at wave 7 (3.98) in the simple linear regression equations. Since we hypothesized that greater

[3] Constraints related to teacher's various levels of education

$$u_1 \geq 3.192$$

$$u_2 \geq 3.070$$

$$u_3 \geq 3.070$$

$$u_6 \geq 2.966$$

[4] Constraints related to teacher's perceived responsibility to teach SECD

$$u_1 \geq 3.342$$

$$u_2 \geq 3.083$$

$$u_3 \geq 3.083$$

resources would result in greater lesson delivery, we developed the equations for resources to be more than or equal to its mean in wave 7. One constraint[5] is obtained for Unit 1. This constraint for Unit 1 is due to inadequate resources. Among the six units, we proceeded with only the first unit because the slope in the simple linear regression equation was in the hypothesized direction.

Teachers also reported how often they felt *safe* at school by responding to four items (e.g., "How often have you been afraid that a student will hurt you at school?" "How often have you brought something to school to protect yourself?"). The response options ranged from 1 = Never to 4 = 6 or More Times. We reverse coded the four items so that higher scores represented more feelings of safety (Cronbach's alpha: 0.77). To form each constraint, we ran a simple linear regression, in which the number of lessons during Unit i (i = 1…6) served as the dependent variable and safety served as the independent variable. We then substituted the actual mean of safety at wave 7 (3.28) in the simple linear regression equations. Since we hypothesized that there would be a direct relationship between safety and lesson delivery, we developed the equations for safety to be more than or equal to its mean in wave 7. Six constraints[6] were obtained for Units 1–6. These constraints for Units 1 through 6 are due to inadequate safety. Note that we selected all six units due to each slope in the simple linear regression models being in the hypothesized direction.

The response options for each decision variable u_i (number of lessons taught on the average week during Unit i [i = 1…6]) ranged from 0 to 5 or more. Given the theory guiding the *PA* program, and that the curriculum intentionally includes all six units, we thought it desirable that at least one lesson of each *PA* unit will be taught on the average week during that unit. Hence, we added appropriate equations to reflect the range for the number of lessons taught in each unit.[7]The final LP model, created to eliminate redundancy among constraints (e.g., according to one constraint $u_1 \geq 3.342$; this makes constraint $u_1 \geq 3.192$, a redundant constraint), is as follows:

[5] Constraint related to school's adequate resources $u_1 \geq 3.218$

[6] Constraints related to school safety

$$u_1 \geq 2.713$$

$$u_2 \geq 2.356$$

$$u_3 \geq 2.356$$

$$u_4 \geq 2.360$$

$$u_5 \geq 2.253$$

$$u_6 \geq 2.188$$

[7] Constraints related to the range of the responses for each decision variable:

$$u_1, \dots, u_6 \geq 1$$

$$u_1, \dots, u_6 \leq 5$$

$$\begin{aligned} & Min \quad -0.123u_1 - 0.128u_2 - 0.138u_3 - 0.152u_4 - 0.152u_5 - 0.152u_6 \\ & \quad\quad\quad Subject\ to \end{aligned}$$

$$3.342 \le u_1 \le 3.356$$

$$3.083 \le u_2 \le 3.197$$

$$3.083 \le u_3 \le 3.197$$

$$2.360 \le u_4 \le 3.213$$

$$2.253 \le u_5 \le 3.182$$

$$2.966 \le u_6 \le 3.112$$

We used Excel Solver (an add-into Excel) to solve the LP model.

Results

Table 1 presents actual values and calculated optimal values for the decision variables. The first column illustrates the actual mean and range for lesson implementation per unit per average week that each particular unit was taught, as reported by teachers. The second column indicates the calculated optimal number of lessons that should be taught on the average week during each unit to minimize substance use. The table shows that for each unit, the actual average number of weekly lessons taught was lower than the calculated optimal number of weekly lessons. In addition, we were interested in observing the individual effect of each unit. Although there was not extensive variation between units, Unit 1 (self-concept) and Unit 4 (pro-social interactions) were the units that results showed should be taught with the greatest frequency to minimize substance use.

Discussion

We conducted a novel exploratory study in order to determine whether it is feasible to apply the LP technique, which is used in management science, to a school health program. We developed a model and calculated the optimal amounts of program implementation needed to minimize substance use, given implementation barriers that exist at the student, teacher, and school levels. Results of this exploratory study demonstrate the feasibility of applying LP to school health programs.

We were also able to calculate the optimal numbers of lessons per unit to be taught weekly (i.e., 3–4) in order to minimize substance use, subject to set values of known implementation barriers. On average, teachers came close to teaching

Table 1 Actual and optimal number of lessons on the average week during each unit that should be taught during the 2008–2009 academic year to minimize substance use at the end of the 2009–2010 academic year

Number of lessons taught on the average week of the 2008–2009 academic year during…	Actual reported number of lessons taught per week per Unit: Mean; Range (Teacher report)	Calculated optimal number of lessons that should be taught per week per Unit
Unit 1: self-concept	2.995; 0–5 or more	3.356
Unit 2: Positive Actions for the body and mind	2.970; 0–5 or more	3.197
Unit 3: self-management	2.968; 0–5 or more	3.197
Unit 4: prosocial interactions	2.960; 0–5 or more	3.213
Unit 5: self-honesty	2.928; 0–5 or more	3.182
Unit 6: self-improvement	2.898; 0–5 or more	3.112

the optimal numbers of weekly lessons from each unit. This may explain, in part, why previous studies from this trial showed an impact on substance use, as compared control schools (Lewis et al., 2012). Teachers who taught less than the optimal amount should be consulted to better understand implementation barriers, and how they can be overcome in future studies.

With respect to the specific findings about individual effect of each unit, results suggest that teaching more lessons from the units on self-concept (Unit 1) and prosocial behavior (Unit 4) may be beneficial. In previous research Fuentes, Garcia, Gracia, and Lila (2011) observed an inverse relationship between substance use and academic, family, and physical self-concept of adolescents. In another study, Ludwig and Pittman (1999) also observed an inverse relationship between prosocial values and adolescent substance use. These preliminary findings support the evidence-based framework guiding the *PA* curriculum and highlight the potential importance of self-concept and pro-social interactions in minimizing adolescent substance use. Given the exploratory nature of this work, and its novelty in that it is the first known application of LP to a trial on a school-based SECD program, it would be important to aim to replicate these findings with other completed trials of *PA* and similar programs to determine reproducibility.

Limitations

The objective function (i.e., grade 8 substance use) of our study was based on student self-report. Additionally, the decision variables (i.e., weekly implementation of lessons from the six units) rely on accurate teacher recall, and do not indicate other components of fidelity (e.g., adherence, perceived quality of lesson delivery, participant engagement; Dusenbury, Brannigan, Falco, & Hansen, 2003). Nonetheless, dosage is considered an important indicator of implementation quality (Domitrovich et al., 2009; Dusenbery et al., 2003). The constraints we selected do not encompass all possible variables that could influence implementation. However, we selected known correlates of implementation that align with an ecological approach. Given the exploratory nature of our analyses, we did not include all possible implementation barriers (e.g., classroom size, absenteeism); it is possible that other variables may be more influential determinants of program implementation in other settings. With respect to our analytic plan, although LP is a theoretical approach that gives an exact solution, our approach did require the use of linear regression to estimate the objective function and constraints coefficients. This makes the coefficients of the objective function and constraints estimates of the actual values. In addition, we made analytic decisions that were based on our interest in examining the individual effect of each unit; as such, we employed simple linear regression analyses. Future studies with different aims could employ multiple regression analyses that also control for possible covariates of a particular objective function (e.g., in our example, prior substance use).

These limitations notwithstanding, our results show that LP, a technique used in both related and unrelated fields, can also be applied as a tool to optimize school-based health programs. Doing so during the planning phase of a school-based health program could potentially lead to improved outcomes, such as the prevention or delayed initiation of high-risk behaviors.

Acknowledgements This study was funded by the ORSP Internal Research Grant Award at California State University, Long Beach. Preparation of this manuscript was supported by a grant from the Institute of Education Sciences (IES): R305A180259. The project from which data were obtained was funded by grants from the Institute of Education Sciences (IES), US Department of Education: R305L030072, R305L030004 and R305A080253 to the University of Illinois at Chicago (2003–2005) and Oregon State University (2005–2012). The initial phase (R305L030072) was a component of the Social and Character Development (SACD) Research Consortium. The SACD Research Program was a collaboration among IES, the Centers for Disease Control and Prevention's (CDC) Division of Violence Prevention, Mathematica Policy Research Inc. (MPR), and awardees of SACD cooperative agreements (Children's Institute, New York University, Oregon State University (OSU), University at Buffalo-SUNY, University of Maryland, University of North Carolina-Chapel Hill, and Vanderbilt University). The SACD research program included multi-program evaluation data collected by MPR and complementary research study data collected by each grantee. The findings reported here are based only on the Chicago portion of the multi-program data and the complementary research data collected by the University of Illinois at Chicago (UIC) and OSU (Brian Flay, Principal Investigator) under the SACD program. Brian Flay and David DuBois conceived the original study and obtained funding, David DuBois and UIC staff oversaw program implementation, the program developer (Carol G. Allred) provided teacher/staff training, UIC and MPR staff collected all data. For this manuscript, Niloofar Bavarian, Banafsheh Behzad and Sheena Cruz performed a secondary analysis of data from the Chicago study. Banafsheh Behzad and Niloofar Bavarian conceived the research question. A scientific poster including some findings reported herein was presented at the 2017 INFORMS Annual Meeting in Houston, Texas. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Institute of Education Sciences, CDC, MPR, or every Consortium member, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government. We are extremely grateful to the participating Chicago Public Schools (CPS) schools, their principals, teachers, students, and parents. We also thank the CPS Research Review Board and Office of Specialized Services.

Compliance With Ethical Standards

Conflict of interest The research described herein was done using the program, the training, and technical support of *Positive Action, Inc*. in which Dr. Flay's (who is not a co-author on this manuscript) spouse holds a significant financial interest. Issues regarding conflict of interest were reported to the relevant institutions and appropriately managed following the institutional guidelines.

Ethical standards The study was approved by the Institutional Review Board at California State University, Long Beach.

References

Beets, M. W., Flay, B. R., Vuchinich, S., Acock, A., Li, K. K., & Allred, C. G. (2008). School climate and teachers' beliefs and attitudes associated with implementation of the Positive Action program: A diffusion of innovations model. *Prevention Science, 9*(4), 264–275. https://doi.org/10.1007/s11121-008-0100-2.

Botvin, G. J. (2004). Advancing prevention science and practice: Challenges, critical issues, and future directions. *Prevention Science, 5*(1), 69–72. https://doi.org/10.1023/B:PREV.0000013984.83251.8b.

Centers for Disease Control and Prevention. (2016). Youth risk behavior surveillance system. https://www.cdc.gov/healthyYouth/data/yrbs/index.htm. Updated 11 August 2016. Accessed 12 July 2017.

Collins, L. M., Kugler, K. C., & Gwadz, M. V. (2015). Optimization of multicomponent behavioral and biobehavioral interventions for the prevention and treatment of HIV/AIDS. *AIDSand Behavior, Supp 1,* 197–214. https://doi.org/10.1007/s10461-015-1145-4.

Cote-Lussier, C., & Fitzpatrick, C. (2016). Feelings of safety at school, socioemotional functioning, and classroom engagement. *Journal of Adolescent Health, 58*(5), 543–550. https://doi.org/10.1016/j.jadohealth.2016.01.003.
Dane, A. V., & Schneider, B. H. (1998). Program integrity in primary and early secondary prevention: Are implementation effects out of control? *Clinical Psychology Review, 18*(1), 23–45. https://doi.org/10.1016/S0272-7358(97)00043-3.
Domitrovich, C. E., Gest, S. D., Gill, S., Jones, D., & DeRousie, R. S. (2009). Individual factors associated with professional development training outcomes of the Head Start REDI Program. *Early Education and Development, 20*(3), 402–430. https://doi.org/10.1080/10409280802680854.
Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: A review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American Journal of Community Psychology, 41*(3–4), 327–350. https://doi.org/10.1007/s10464-008-9165-0.
Dusenbury, L., Brannigan, R., Falco, M., & Hansen, W. B. (2003). A review of research on fidelity of implementation: Implications for drug abuse prevention in school settings. *Health Education Research, 18*(2), 237–256. https://doi.org/10.1093/her/18.2.237.
Earnshaw, S. R., Hicks, K., Richter, A., & Honeycutt, A. (2007). A linear programming model for allocating HIV prevention funds with state agencies: A pilot study. *Health Care Management Science, 10*(3), 239–252. https://doi.org/10.1007/s10729-007-9017-8.
Flessa, S. (2000). Where efficiency saves lives: A linear programme for the optimal allocation of health care resources in developing countries. *Health Care Management Science, 3*(3), 249–267. https://doi.org/10.1023/A:1019053710258.
Fuentes, M. C., Garcia, F., Gracia, E., & Lila, M. (2011). Self-concept and drug use in adolescence. *Adicciones, 23*(3), 237.
Hillier, F. S., & Lieberman, G. J. (2005). *Introduction to operations research*. New York: McGraw Hill.
Kuo, P. C., Schroeder, R. A., Mahaffey, S., & Bollinger, R. R. (2003). Optimization of operating room allocation using linear programming techniques. *Journal of the American College of Surgeons, 197*(6), 889–895. https://doi.org/10.1016/j.jamcollsurg.2003.07.006.
Lewis, K. M., Bavarian, N., Snyder, F. J., Acock, A., Day, J., Dubois, D. L., et al. (2012). Direct and mediated effects of a social-emotional and character development program on adolescent substance use. *The International Journal of Emotional Education, 4*(1), 56.
Linnell, J. D., Smith, M. H., Briggs, M., Brian, K. M., Scherr, R. E., Dharmar, M., et al. (2016). Evaluating the relationships among teacher characteristics, implementation factors, and student outcomes of children participating in an experiential school-based nutrition program. *Pedagogy in Health Promotion, 2*(4), 256–265. https://doi.org/10.1177/2373379916649603.
Ludwig, K. B., & Pittman, J. F. (1999). Adolescent prosocial values and self-efficacy in relation to delinquency, risky sexual behavior, and drug use. *Youth and Society, 30*(4), 461–482. https://doi.org/10.1177/0044118X99030004004.
Malloy, M., Acock, A., DuBois, D. L., Vuchinich, S., Silverthorn, N., Ji, P., et al. (2015). Teachers' perceptions of school organizational climate as predictors of dosage and quality of implementation of a social-emotional and character development program. *Prevention Science, 16*(8), 1086–1095. https://doi.org/10.1007/s11121-014-0534-7.
Massachusetts Institute of Technology. (1977). Mathematical programming: an overview. Retrieved December 17, 2019 from http://web.mit.edu/15.053/www/AppliedMathematicalProgramming.pdf.
Mulholland, M. W., Abrahamse, P., & Bahl, V. (2005). Linear programming to optimize performance in a Department of Surgery. *Journal of the American College of Surgeons, 200*(6), 861–868. https://doi.org/10.1016/j.jamcollsurg.2005.01.001.
Pas, E. T., Waasdorp, T. E., & Bradshaw, C. P. (2015). Examining contextual influences on classroom-based implementation of positive behavior support strategies: Findings from a randomized controlled effectiveness trial. *Prevention Science, 16*(8), 1096–1106. https://doi.org/10.1007/s11121-014-0492-0.
Payne, A. A., Gottfredson, D. C., & Gottfredson, G. D. (2006). School predictors of the intensity of implementation of school-based prevention programs: Results from a national study. *Prevention Science, 7*(2), 225–237. https://doi.org/10.1007/s11121-006-0029-2.
Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling*. New York: Wiley.
Tianviwat, S., Chongsuvivatwong, V., & Birch, S. (2009). Optimizing the mix of basic dental services for Southern Thai schoolchildren based on resource consumption, service needs, and parental

preference. *Community Dentistry and Oral Epidemiology, 37*(4), 372–380. https://doi.org/10.1111/j.1600-0528.2009.00481.x.

Wang, B., Stanton, B., Deveaux, L., Lunn, S., Rolle, G., Adderley, R., et al. (2017). Multi-year school-based implementation and student outcomes of an evidence-based risk reduction intervention. *Implementation Science, 12*(1), 16. https://doi.org/10.1186/s13012-016-0539-7.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.