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Modeling Mathematics and Computational Thinking

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ABSTRACT

The essence of computational thinking, according to the paper, is mathematical modeling. Learning a computer language is helpful for developing logical reasoning skills, but it is less helpful for developing problem-solving abilities. This paper, which is the third in a series, offers some advanced spreadsheet-based mathematical modeling examples from high school or early college.

Keywords: Computational-Thinking; Mathematical-Model; Problem-Solving; Spreadsheet-Solution

INTRODUCTION

Two previously published publications, Sanford (2013) and Sanford and Naidu (2016), focused on the claim that mathematical modeling is a crucial component of computational thinking. Mathematical models or scientific methods are used in the majority of problem-solving situations. Using contemporary digital techniques to solve problems is known as computational thinking. The model is merely an essential component of the procedure. Teachers generally agree that computational thinking should start early in a child's formal education.

Teaching computer programming seems to be a major focus. Here, two recommended curricula are cited as examples: Code.org Computer Science Principals (2016) and Joanna Goode J., Chapmen G. (2011). For a plethora of related works, the reader merely needs to Google the subject.

PROBLEM SOLVING WITH COMPUTATIONAL THINKING

Problem definition is the first step in the problem-solving process. The dimensions and characteristics that affect or could affect the issue are identified in the following stage. Finding the factors that are most likely important is the third phase. The technique to problem-solving examines the connections between the parameters. These connections either form or evolve into the model.

Every year, the number of computer programming languages increases. By the time a twelve-year-old graduates from college, the computer language she was taught is probably not going to be widely used. Nonetheless, key components of the systems approach to problem-solving, such as the notion of logical or mathematical modeling, are likely to stay relevant. Weather forecasting models, the "Standard Model" of theoretical physics, financial models used in banking and finance, etc. are a few examples of important mathematical models in use today.

Practically speaking, spreadsheets are used in a lot of basic business concepts. They are simple to operate and provide visibility. The current writers have argued for the use of spreadsheets as an instructional aid in earlier work. The spreadsheet offers a very visual representation of the model along with a simple way to expand and modify it.

An Example Suitable for High School or Early College

To illustrate the usefulness of spreadsheets, a model development technique is described below. It is anticipated that high school and college students have experience with spreadsheet programming.

Let's say a manufacturer intends to launch a new product. This process involves a number of components, some of which are listed below.

- Estimated sales volume over at least the early life of the product
- Materials involved and their cost
- Manufacturing methods and costs
- Distribution channels and costs
- Taxes and maintenance cost

Table 1. Sales

Month	Sales
1	6,700
2	9,300
3	12,400
4	16,200
5	20,500
6	25,300
7	30,300
8	35300
9	40,000
10	44,100
11	47,200
12	49,300

(Table 1 continued on next page)

(Table 1 continued)

Month	Sales
13	50,000
14	49,300
15	47,200
16	44,100
17	40,000
18	35,300
19	30,300
20	25,300
21	20,500
22	16,200
23	12,400
24	9,300

It requires extensive analysis to specify numerical values for these factors. Traditionally, different potential approaches are traded off. Overhead costs are not included in the study if the new product is merely a small portion of the overall number of corporate products. Depending on the corporation's tax bracket, the model may incorporate marginal taxes. Assuming that new equipment won't need maintenance for a brief endeavor, a simple model does not include maintenance. If there is a mechanism to estimate maintenance, it might be added.

The use of mathematical modeling to help management choose between two ways to manufacture the new product is illustrated in the following sub-problem. The model makes the assumption that the fundamental production process has been established by production engineers. Additionally, the model makes the assumption that two potential production techniques are worthwhile. One approach will have a low labor cost but a high upfront cost for new machinery. The alternative approach will cost more for labor but require less expensive equipment.

Additionally, as indicated in Table 1, the model requires that marketing personnel have supplied an estimate of sales volume for at least the early stage of product life. There is usually some degree of uncertainty in sales estimates. The model's ease of inserting new figures to replace the old values and get new outcomes is one of its advantages.

The different parameters are parts of what technologists call the state vector or state space. One of these factors is sales.

The mathematical model consists of two equations.

(1) Unit profit = Unit price – Unit labor cost – Unit material cost
(2) Monthly profit = Unit profit * Sales volume for the month (where * indicates multiplication).

Figure 1. Showing state variables

	A	B	C	D
1	STATE VECTOR			
2	Month end >>>		1	2
3				
4	unit sales by month		6,700	9,300
5	setup cost A	150000		
6	Monthly Maintenance	not computed		
7	unit material cost/unit A	2.30		
8	unit labor cost/unit A	1.30		
9	unit price	4.99		
10	unit profit A	1.39		
11	Share of Taxes	not computed		
12	Monthly Profit A		9,313	12,927
13	Cumulative profit A		(140,687)	(127,760)
14				
15	setup cost B	25000		
16	unit material cost/unit B	2.30		
17	unit labor cost/unit B	1.80		
18	Unit profit/unit B	0.89		
19	Monthly Profit B		5,963	8,277
20	Cumulative profit B		(19,037)	(10,760)

Figure 2. Estimated Sales

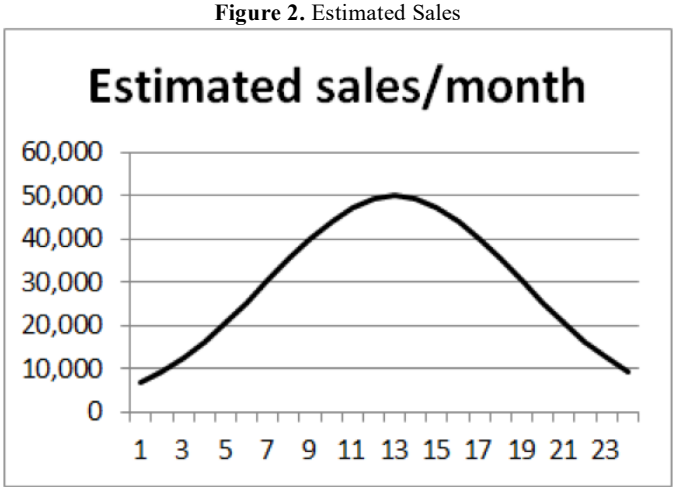


Figure 1 shows the state vector (i.e. a list of parameters) for the problem. Unit profit is a calculated quantity using Unit Sales price, Unit material cost, and Unit and labor cost. Associated figures are Figure 2 showing projected sales and Figure 3 showing the cumulative profit for manufacturing methods A and B. It is important to note that Figure 1

shows sales for only two months. The entire spreadsheet would be quite wide because it contains a separate column for each of the 24 months. Figure 1 displays only the top left of the entire model spreadsheet.

All formulas refer to the parameter values located in the area shown in Figure 1, or refer to values in the labeled rows such as the row labeled "unit sales by month." Changing the value of any parameter will produce new calculations and a new set of model results.

Figure 3. Comparing A and B

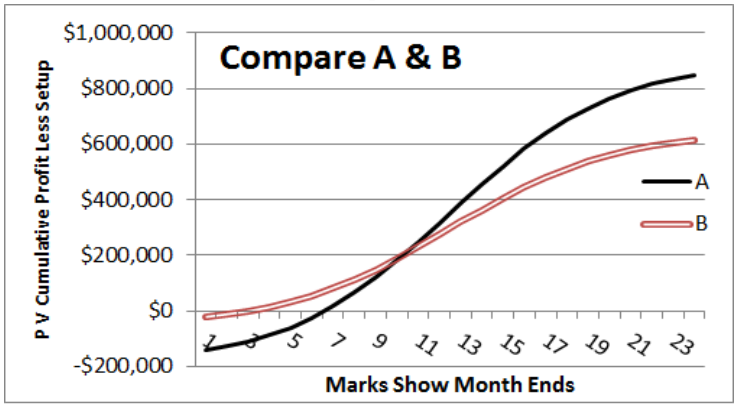


Table 2. Sales

Month	Sales
1	30,000
2	40,000
3	46,000
4	49,000
5	50,000
6	49,000
7	47,000
8	44,000
9	40,000
10	35,000
11	30,000
12	25,000
13	21,000
14	16,000
15	12,000
16	9,000
17	7,000
18	4,000
19	2,000
20	1,000
21	-

This sample problem reveals the power of graphical display for data and results. Graphs provide visual impact and allow the viewer to grasp significant features that represent a totality of the model results. A graphing capability is available in all existing spreadsheet software packages.

Figure 3 reveals that process B has a "break-even point" much sooner than process A. However, based on marketing sales projection, Process A yields far more profit over time. Students can see this easily from the graph. Students

should consider the significance of a "break-even point." Is that point important or is total profit important? How much confidence would they have in the marketing projection? Perhaps the marketing people are overly optimistic. Should they consider different marketing projections? Discussing such questions and making these changes on the Excel spreadsheet would significantly improve the classroom experience.

After implementing the model, the analyst can easily examine results under different sales volume assumptions. The analyst simply inserts new sales estimates in place of the existing ones to obtain a new solution. For example, the sales estimate shown in Table 2 will produce the new results shown in Figure 5. Figure 4 presents the sales estimate in graphical form. Note that Figure 4 is quite different from Figure 2.

Figure 4. Different sales estimate

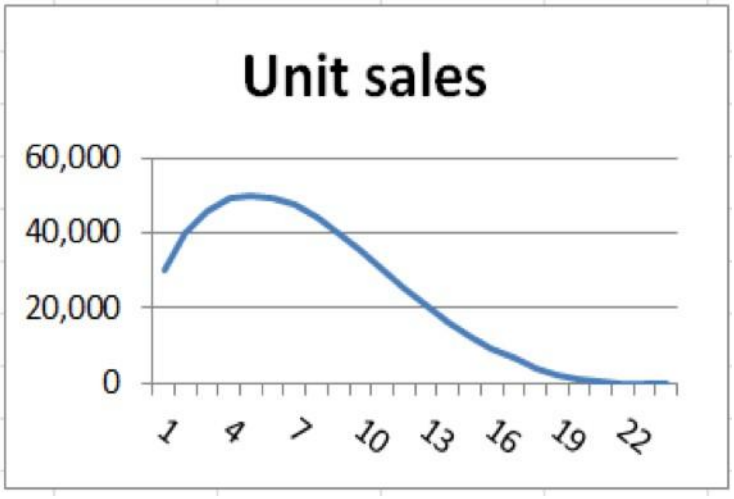
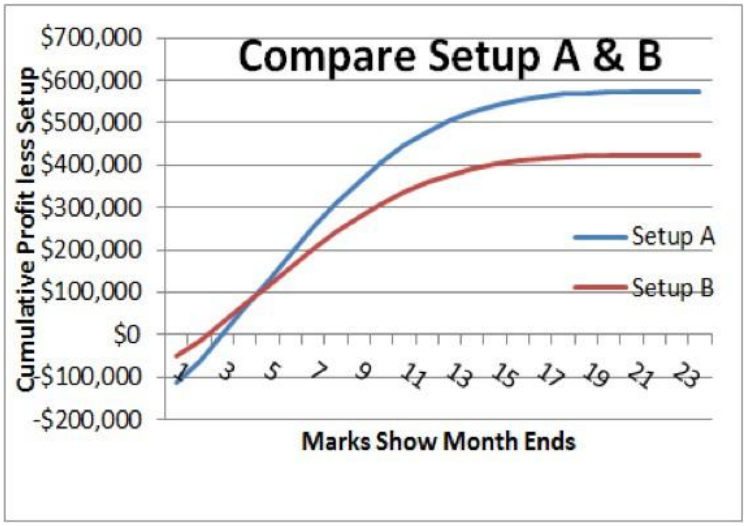


Figure 5. With sales shown in Figure 4



The analyst can change other parameters to produce other new results as part of the decision-making process. Spreadsheets have add-in procedures that allow the application of random variables to describe parameters such as unit labor cost or unit price. The add-in procedure runs the model numerous times and presents a statistical plot of results.

The agile approach to systems development involves, among other things, alteration to first design as a result of output evaluation. The model approach is a valid vehicle for agile design because it is easy to create additions and alterations to the model.

Present Value Analysis

Suppose students are asked to consider the time value of money. If a person deposits P dollars in a bank with an interest rate of i, what will the total value be in 1 year? For example, \$10,000 with a 2% annual interest rate will yield \$10,000 * 1.02 = \$10,200 in one year and \$10,000 * 1.02 * 1.02 = \$10,404 in two years. This is $10,000 * 1.02^2 = 10,404$. In reverse, $10,404/1.02^2$ = the original 10,000. The present value equals the future value divided by $(1+i)^n$. Banks are allowed to use a monthly interest rate of $i/12$. Using that monthly rate results in a true annual rate above the value of i, however it is common practice to use $i/12$.

The new equation in the model is:

(3) Present \$ = monthly $/(1+(i/12))^n$

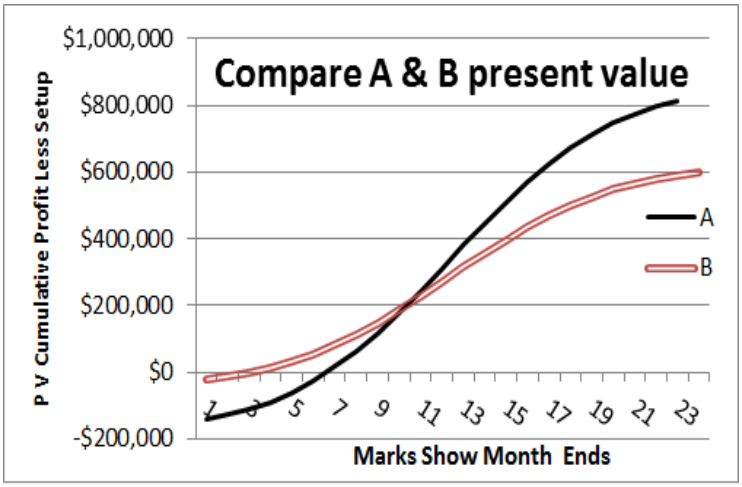
where n is the month-end number.

The spreadsheet will require two additional rows. One additional row must contain each month's profit stated as a present value according to equation 3. The second additional row must accumulate present values of all preceding months. Interest rate is added to the state vector. Figures 6 and 7 show the results of analysis using the sales estimate of Figure 2 with present value considered.

Figure 6. (Table 1 sales with present value calculation)

	A	B	C	D
1	STATE VECTOR			
2	Month end >>>		1	2
3	Yearly interest rate	2%		
4	Monthly Interest rate	0.167%		
5	unit sales		6,700	9,300
6	setup cost A	150000		
7	Monthly Maintenance	not computed		
8	unit material cost/unit A	2.30		
9	unit labor cost/unit A	1.30		
10	unit price	4.99		
11	unit profit A	1.39		
12	Share of Taxes	not computed		
13	Monthly profit A		9,313	12,927
14	Cumulative profit A		(140,687)	(127,760)
15	Present value monthly profit		9,298	12,884
16	Cumulative present value		(140,702)	(127,818)
17				
18	setup cost B	25000		
19	unit material cost/unit B	2.30		
20	unit labor cost/unit B	1.80		
21	Unit profit/unit B	0.89		
22	Monthly profit B		5,963	8,277
23	Cumulative profit B		(19,037)	(10,760)
24	Present value monthly profit		5,953	8,249
25	Cumulative present value		(19,047)	(10,797)

Figure 7. With sales of Figure 2 & present value



The present value concept can be easily used in an introductory Finance class. The value of this exercise lies in its demonstration of the versatility of mathematical models along with the graphical features of a spreadsheet.

An Example from Natural Sciences

The natural sciences offer varied and even exciting opportunities for computational thinking in the typical high school setting. The simple example of a ball thrown straight up into the air uses the Newton's mathematical model for motion, Velocity = acceleration * time. This model deals with the acceleration of gravity and initial velocity. The letter g represents the acceleration of gravity which is approximately 32.174 feet per second per second at or near the surface of the earth. The total velocity, V_t, of the object thrown upward is the sum of the initial velocity V_1 plus the velocity imparted by gravity which is the acceleration of gravity times t. At the apex, the velocity is zero. Hence, at the apex, $V_1 + g*t = 0$. If the model assumes the direction of V_t to be positive (upward direction), then the direction of g*t is negative (downwards).

Figure 8 shows the spreadsheet model. State variables appear at the top left. The model uses dynamic programming to depict the position and velocity of the ball at the end of equal-length segments of time. The time segment is defined as a step. The rows are numbered only for clarity. Equations 4 through 8 define the mathematical modal. This model omits the effect of air drag.

(4) $V_g = - g*t$ (Velocity resulting from g alone)
(5) Total = $V = V_1 + V_g$ (V_g has negative value)
(6) Distance = $D = V_1 * t - 0.5 * g * t^2$
(7) At the apex $V_1 = g*t$
(8) $T_T = 2 * V_1/g$

Equation 8 is true because the return trip made by the ball is identical to the trip going up, except for direction. The apex occurs at half the total time.

The maximum vertical distance is the same as the distance through which the ball would free-fall in time $t = ½ T_T$. This maximum vertical distance is $½ * g * t^2$. Calculus is required to derive the maximum vertical distance. However, the formula is typically found even in high school general science books.

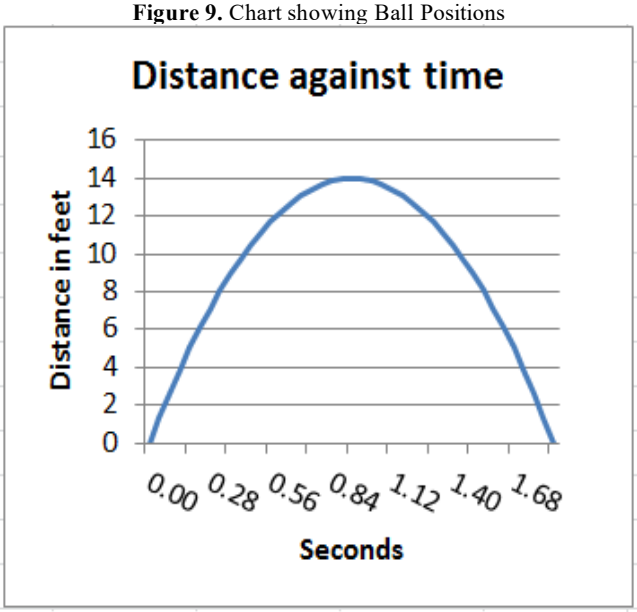
It would be good to have a chart of the ball's flight, distance versus time (Figure 9). And it would be good to have the model independent of the value of V_1. If the step size is equal to $T_T/40$, there will be 41 positions on the chart. It doesn't have to be forty, and any number will do. There are forty- one instead of forty positions because the first

position (first row) is an initial condition and at the start of a time unit. All the other numbers relate to the end of a time unit.

Figure 8. Dynamic Programming Model

	A	B	C	D	E
1	How high will a ball go when thrown straight up?				
2					
3	State Variables				
4	gravity acceleration		g	32.174	ft./sec^2
5	velocity at start		V_1	30	ft./sec
6	Total time		T_T	1.86486	sec
7	Number of points		P	40	
8	Graphical Step		S	0.046621	This is T_T/P
9	Air resistance			not included	
10	Velocity due to gravit		Vg	in columns below	
11	Total Velocity		V	in columns below	
12	position in feet		D	in columns below	
13					
14	Row num.	t in sec	Vg	V	D
15	0	0.00	0.000	30.000	0.000
16	1	0.05	-1.500	28.500	1.364
17	2	0.09	-3.000	27.000	2.657
18	3	0.14	-4.500	25.500	3.881

Figure 9. Chart showing Ball Positions



CONCLUSION

The majority of issues that arise in our world are analytical in nature and can typically be roughly explained by a mathematical model. Early introduction of computational thinking principles in the educational process is desirable. While understanding computer science principles is beneficial, it does not prioritize mathematical modeling or problem solving on its own. Spreadsheets can be used to teach the important ideas of mathematical modeling and computational thinking in addition to problem-solving, which is typically included in high school and early college curriculum.

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