Keeping Students with the Curriculum

Using a systems dynamics approach to elementary education.

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A study was performed by the authors as an exploration into the systems dynamics of elementary education. The objective of this study was to analyze which factors help students keep up with the curriculum best in the context of a systems dynamics model. Because of the assumption that schools have very little influence on the socio-economic factors in their area, only factors which can be influenced by professionals in education were considered for this study. The long term vision of this study is to enable professionals in education to see a range of possible results of changes to the school on keeping students with the curriculum (possibly through an online tool). To achieve this, a systems dynamics model of a generic elementary school was built using Vensim. The model was tested under a series of systematically altered conditions and sensitivity analyses were performed. Difficulties in measuring psychological factors necessitated assumptions regarding certain factors such as levels of teacher enthusiasm. The major findings of the study, are that teacher training in an archetypal *good* school and a combination of policy measures in an archetypal *bad* school have the largest influence on students keeping up with the curriculum.

1 Problem Description

This study attempts to address the problem of students falling behind the curriculum of a school. Society has an interest in these students becoming productive members of society. The importance of keeping children at grade level (called *with the curriculum* in this paper) cannot be overemphasized [1, 2]. According to Graves, increasing the graduation rate by 10% would reduce the number of murders in Oregon by 17 and aggravated assaults by 1,300 per year[1]. Further, a study from Northeastern University shows the seriousness of the correlation between not completing high school and being incarcerated. Those who did not complete high school were 63% more likely to spend time in prison than those who completed college [3].

While these studies deal with completing high school, early intervention is key. As stated by the American Federation of Teachers: "waiting rarely works" [4], meaning children that are behind need to catch up as early as possible. Simply waiting for students to do this themselves results in these students only falling further behind and consequently later decreases their chances of completing high school. In this study, intervention in elementary school is analyzed. Earlier intervention is also possible but outside the scope of this study.

1.1 Goals and Research Question

The vision of this study is to offer insight into education for educational professionals with the hope that they can see the impact of changes to their school system (in the context of the model) on keeping students with the curriculum. In the future, this could possibly be accomplished through an online tool. Socio-economical factors are not included, as in general these cannot be influenced by a school.

The goal of this study is to build a model of a generic elementary school using Vensim. The structure of this model should allow educational professionals to:

- Input their school specific parameters, such as initial students and teachers.
- See how changes in policy measures such as teacher training or instruction material affect student learning.

Lastly a long term goal of this this study is to ensure students grow up to be productive members of society through education. Therefore the model should help to show which policies prevent students from falling behind.

This study attempts to answer the research question: *Which parameters that we can influence affect whether students perform with the curriculum or fall behind?*

2 Model

2.1 Approach

This study creates a rough, first-look model of elementary schools. System dynamics was chosen instead of other methods, such as agent based modeling, as this study does not focus on the individual but instead on the way the system interacts as a whole. For example, student fractions were used to represent the student body. Furthermore, teaching levels are used to influence the student fractions, not individual teachers. The system focuses on feedback loops; these are explained further in section 2.4 of this paper. The National Institute for School Leadership in the US also depicts the feedback relation of *Professional Development* and *Leadership* to student achievement *College Readiness* [5]. Thus, to represent the system dynamics of a generic elementary school, a model was constructed in Vensim. The text view of this model can be found in the appendix.

2.1.1 System Boundary

The scope of this study is limited to a generic elementary school. The scope of this model is twelve years, allowing for two full cycles of students to move through the school. The concept of the model is to keep students with the curriculum.

Within this framework it is assumed that any student with the proper help can keep up with the curriculum. Severely disabled children are outside the scope of this study. Parental support of students, although affecting student learning, is also not included. This is assumed to be a societal issue that is not within the scope of this model. Thus extra teachers dependent on the number of behind and challenged students are used to compensate for a potential lack of parent support.

2.2 Factors that Influence Student Learning and Teacher Development

The factors contributing to student learning were first determine. This study was limited to the following factors:

- Instruction material [6]
- Teacher training
- Level of overall school improvement support from the administrator [7]
- Teacher enthusiasm
- Student teacher ratio [8]
- Good teachers [9]

In the model, these factors influence student learning by contributing to the variable *effective teaching*, which then directly influences student learning. Because student learning is increased by teachers becoming better teachers - *good teachers*, and because teachers become better teachers through training, the factors that influence the effectiveness of teacher training are considered:

- Amount of teacher training given
- Level of overall school improvement support from the administrator [7]
- Openness of teachers to receive training [8]
- Teacher enthusiasm

2.3 Conceptual Model

Using the influencing factors mentioned above, figure 1 shows a conceptual depiction of the Vensim model built for this study. The figure shows that the main influence in the scope of this study on student learning is effective teaching. This in turn is effected by six parameters, with *administrator support* as an overarching parameter:

- Administrator support
  - Instruction material
  - Teacher training
    - Level of openness of teachers
  - Teacher enthusiasm
  - Good teachers

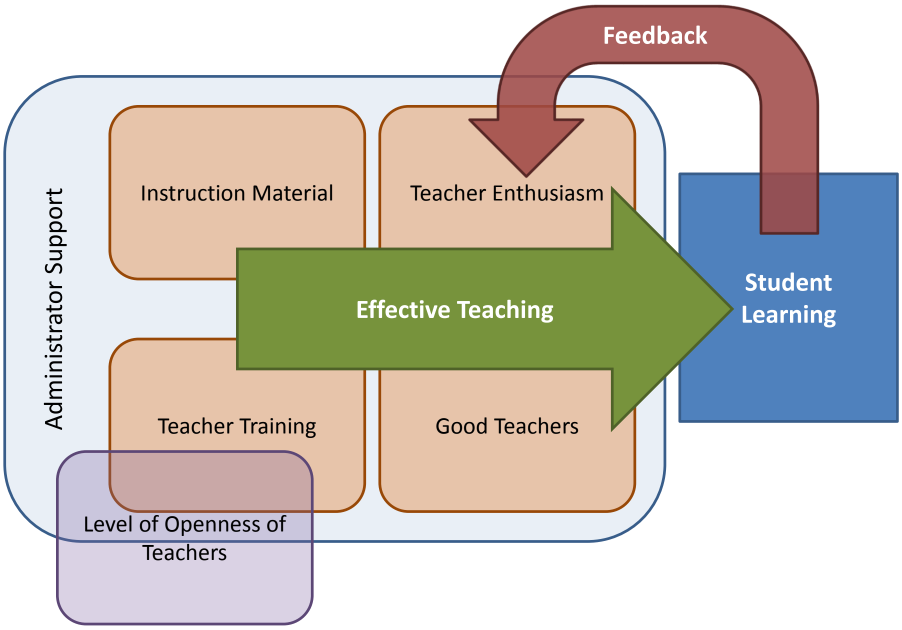

Figure 1: Conceptual Model of Vensim Elementary School Model

2.4 Structure

Figure 2 depicts the full Vensim model built to represent a generic elementary school for this study. A legend explaining the coloring of the model can be found in table 1. The certainty column of table 1 shows which factors are known versus those where measuring is not possible or clear.

Table 1: Legend for Full Vensim Model of a Generic Elementary School

TYPE	COLOR	VARIABLE	CERTAINTY
Initial Inputs	Green	Initial students Inflow rate	Certain: school specific
		Dropout fraction per year Initial school reputation	Uncertain: school specific
		Teacher market Outside job opportunities	Uncertain: area specific
Policy Measures	Dark Red (*italic*)	Instruction material per student Teacher Training	Certain: school specific
		Administrator Fraction of students passing Teacher openness to training TALENTED Teacher openness to training UNTALENTED	Uncertain: school specific
Model KPIs	Orange	Actual student improvement Good teacher ratio Ratio of with the curriculum to total	Certain: school specific
		Effective teaching Teacher enthusiasm School reputation	Uncertain
Weighting factors	Gray	These factors, shown in gray determine the amount of influence a parameter has on either teacher enthusiasm or effective teaching	Uncertain

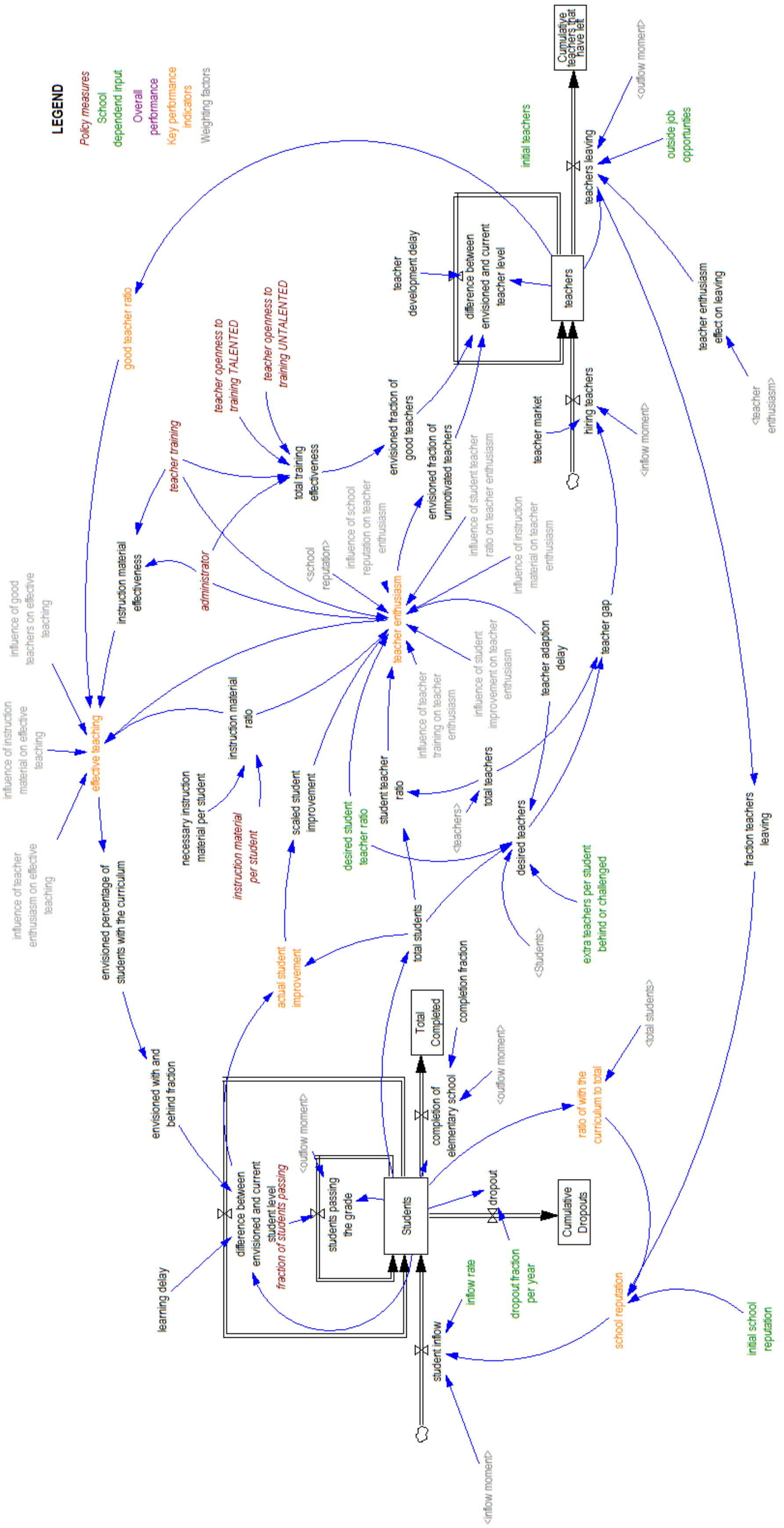

Figure 2: Full Model

2.4.1 Feedback Loops

Figure 3 below shows the main feedback loops of the model.

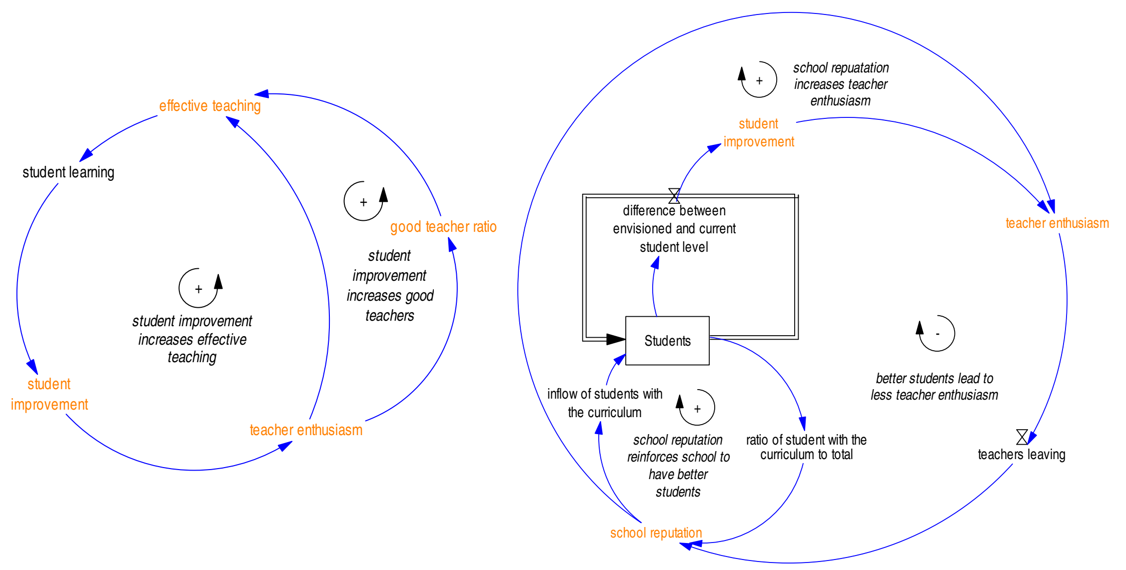

Figure 3: Feedback Loops

On the left, the *student improvement increases effective teaching* loop shows: as teachers teach better, they see results in their students, which fulfills them and makes them more enthusiastic about teaching, which again makes them teach even better. The loop tends towards stagnation as teachers reach a limit of enthusiasm, with fully improved students. The *student improvement increases good teachers* loop shows the same effect, but adds that as teachers are more enthusiastic, they become better teachers, which in turn makes them teach better.

On the right, the *school reputation increases teacher enthusiasm* loop shows that when the school, as a whole, is doing well then teachers become more enthusiastic and are more likely to stay at the school, which in turn keeps the school reputation high. When students are not improving, however, the motivation of teachers also decreases. Other factors such as the student teacher ratio and outside job opportunities also impact this. The *school reputation reinforces school to have better students* loop shows that when the school as a whole is doing well then higher percentages of students *with* the curriculum, enter the school. Socioeconomically advantaged parents, who usually have children who are *with* the curriculum will keep their students in these schools. The *better students lead to less teacher enthusiasm* loop shows that when students are improving, teachers feel fulfilled, but that when the students are already *with* the curriculum, then teachers do not have as large of an impact on their learning and hence their enthusiasm is stagnant (albeit at a high level, it no longer increases).

2.4.2 Subscript Structure

Figure 4 below shows the student subscript structure.

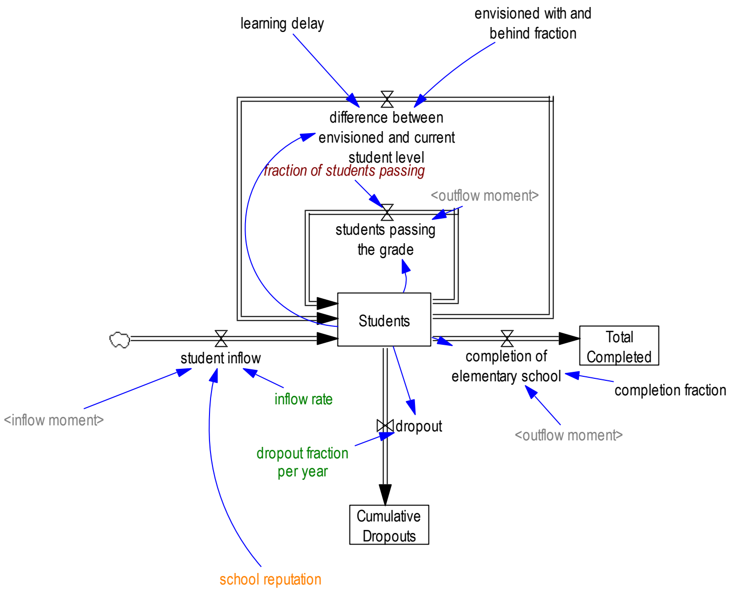

Figure 4: Subscript Structure

Students are composed of a certain amount from each group of the following groups (the total of each group is the total students):

- Performance (with, behind)
- State (challenged, normal)
- Grade (grades 1 through 6)

Certain amounts of students enter the school at the beginning of each year (inflow moment) by the inflow rate, which is an *initial input* specific to the school. Students enter with fixed amounts of challenged or normal, as this is a physiological measure. The amount of students who enter as behind or with, however, depends on the reputation of the school. This shows that as schools perform worse, children who are with the curriculum (generally socio-economically advantaged children) will find other schools to attend. Certain amounts of students move through grades based on the group *performance* via *students passing the grade* which moves students to the next grade at the end of each year [*outflow moment*] by the *fraction of students pass*. For example, if the *fraction of students pass* is 0.5 for students *behind* the curriculum, fifty percent of students behind the curriculum pass; this accounts for students who are not quite *behind* enough to repeat an entire year.

Levels of students in each *state* change via *difference between envisioned and current student level*. The envisioned amount that should be in certain group [*with* or *behind*] is based on the level of teaching *effective teaching*. The envisioned amount is compared to the current amount in each *state* in the school. This difference, with a learning delay, is then fed back into the school, moving closer to the envisioned amount. If students move from *behind* to *with*, they leave *behind* and enter *with*. Thus the sum of all the *difference between envisioned and current student level* should be zero. Students do not move between challenged or normal (as this a physiological state). Students drop out of elementary school based on a certain fraction, given as an *initial input* variable. Unless otherwise specified, only students *behind* dropout. Students can dropout at any point in the year. Certain amounts of students complete elementary school at the end of each year [*outflow moment*] by the completion fraction. The teacher subscript structure follows the student structure with teachers in the following groups:

- Teacher types (good, average, unmotivated)
- Ability (talented, untalented)
- Career stage (mobile, fixed)

2.5 Specification

In table 2, selected equations from the Vensim model used for this study are explained. Further information on specification can be found in the appendix.

3 Model Behavior

3.1 Complete School

Because exact school data is confidential, system dynamics modeling is a useful method to maintain the anonymity of schools. Thus, two archetypal schools were created to analyze the behavior of a *complete school* in the model. The values from these schools were composed to reflect what is deemed a *good* school (table 3) and a *bad* school (table 4).

The model was run for a time span of twelve years to ensure two full cycles of elementary school (one cycle is considered six years) were completed. The variable *Ratio of with the Curriculum to Total* is used to demonstrate the behavior of the schools in the model. Figure 5 depicts the ratio of students who are *with* the curriculum to total students in each school.

Results observed in figure 5 show the *good* school with a ratio of approximately 0.8 and the *bad* school with a ratio of approximately 0.65. The oscillations, particularly seen in the *good* school, result from both teacher and student learning delays. The slight disturbances seen occur from the inflow and outflow of students exactly at the beginning of each year and at the end.

Table 2: Selected Equations with Explanations

VARIABLE	EXPLANATION OF EQUATIONS
Teacher enthusiasm	A smoothed (by teacher adaption delay) fraction that takes into account: • instruction material • teacher training • student teacher ratio (only if this is unacceptably high) • student improvement • school reputation Administrator support affects the entire range of enthusiasm.
Effective teaching	A fraction that takes into account: • instruction material • good teachers • teacher enthusiasm
Difference between envisioned and current student level	As explained in section 2.4, this variable compares the envisioned amount of students in a certain *state* (the envisioned amount is based on the level of effective teaching) and moves toward the envisioned level with a learning delay.
Inflow/outflow moment	These moments use pulses to show the inflow and outflow (or flow to the next grade level) of students at the beginning and end of each school year. Because these happen at the beginning or end of the school year, these moments cause spikes that can be seen in other variables, such as the total students completed.

Table 3: Archetypal *Good* School

TYPE	INPUT VARIABLE	VALUE
Quantitative	Total students	600
	Students Per Year	100
	Percent of students *challenged*	5%
	Percent of students *behind the curriculum*	12%
	Student to teacher ratio	25
	Dropout fraction [*behind* students] (per year)	0
	Percent of students who enter the school [*normal*]	95%
	Percent of students who enter the school [*challenged*]	5%
	Extra teachers per student *behind* or *challenged*	0.5
Qualitative	School reputation	0.8
	Instruction material per student	0.9
	Administrator support	0.9 [10]
	Teacher training	0.7
	Teacher openness to training TALENTED	0.9
	Teacher openness to training UNTALENTED	0.7
	Fraction of *behind* students passing	0.97 [11]

Table 4: Archetypal *Bad* School

TYPE	INPUT VARIABLE	VALUE
Quantitative	Total students	600
	Students Per Year	100
	Percent of students *challenged*	8%
	Percent of students *behind the curriculum*	35%
	Student to teacher ratio	30
	Dropout fraction [*behind* students] (per year)	0.03
	Percent of students who enter the school [*normal*]	92%
	Percent of students who enter the school [*challenged*]	8%
	Extra teachers per student *behind* or *challenged*	0
Qualitative	School reputation	0.6
	Instruction material per student	0.5
	Administrator support	0.8 [10]
	Teacher training	0.7
	Teacher openness to training TALENTED	0.5
	Teacher openness to training UNTALENTED	0.2
	Fraction of *behind* students passing	0.97 [11]

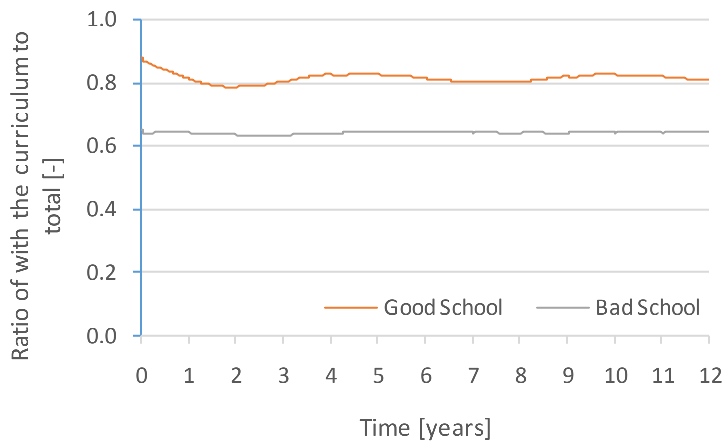

Figure 5: Ratio of *With* Students to Total Students in a *Good* and *Bad* School

3.2 Single Class of Students Flowing Through the School

For the behavioral analysis of a *single class flowing through the school*, an archetypal [*good*] school, found in table 5, was used. Here one full year of students enter the school. Their progress is tracked by measuring how many move on to the next year, how many fall behind and eventually how many complete elementary school.

Table 5: Archetypal Single Class

TYPE	INPUT VARIABLE	VALUE
Quantitative	Total students	100
	Percent of students *challenged*	5%
	Percent of students *behind the curriculum*	20%
	Student to teacher ratio	25
	Dropout fraction [*behind* students] (per year)	0
	Extra teachers per student *behind* or *challenged*	0.5
Qualitative	School reputation	0.8
	Instruction material per student	0.9
	Administrator support	0.9 [10]
	Teacher training	0.7
	Teacher openness to training TALENTED	0.9
	Teacher openness to training UNTALENTED	0.7
	Fraction of *behind* students passing	0.97 [11]

The Vensim model was run for a time span of seven years, allowing for one additional year to measure how many students complete one year behind. A Sankey diagram is used to illustrate this flow of students, as shown in figure 6.

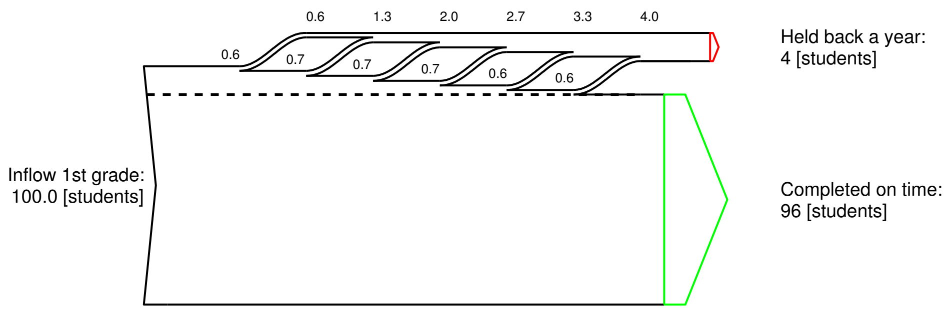

Figure 6: Sankey Diagram Showing a Single Year of Students Flowing Through Elementary School

Figure 6 shows the year starting with 100 students. These students then move to the next year. The upward flow of students represents the students one year behind. As seen in the figure, by the end of the six years of elementary school, 96 students are *with* the curriculum, while 4 are *behind*. Considering that the *good* archetypal school included 8% challenged students, of which 3% were behind before entering the school, this behavior is reasonable. The flows occur at given time intervals due to the inflow and outflow of students to the next grade level exactly at the beginning and at the end of each year.

4 Policy Options

To determine which policy measures would be effective in the archetypal schools from tables 3 and 4, a sensitivity analysis was conducted. The policy measures used are the *Policy Measures* found in table 1. This sensitivity analysis was conducted with the *good* and*bad* school types found in tables 3 and 4.

The output variables of the sensitivity analysis were:

- Ratio of students *with* the curriculum to total students
- Total students completed [*with*]
- Total students completed [*behind*]
- School reputation

Using the distributions for the sensitivity inputs found in table 6, the sensitivity analysis was completed using 200 runs, a twenty year time span, the latin hypercube method and the noise seed 1234.

Table 6: Policy Measures and Distribution of Sensitivity Inputs

POLICY MEASURE (SENSITIVITY INPUT)	DISTRIBUTION OF SENSITIVITY INPUTS
Instruction material per student	RANDOM_UNIFORM (0.3,1.0)
Teacher Training	RANDOM_UNIFORM (0.2,1.0)
Administrator	RANDOM_UNIFORM (0.4,1.0)
Fraction of students behind passing	RANDOM_UNIFORM (0.2,1.0)
Teacher openness to training TALENTED	RANDOM_UNIFORM (0.4,1.0)
Teacher openness to training UNTALENTED	RANDOM_UNIFORM (0.2,0.7)

Using the settings and distributions mentioned, the spread of the *final time* of the sensitivity analysis runs were measured. This represents the condition of the students (in terms of *with* or *behind*) after the time span of the runs are complete. This was done for each individual policy measure as well as for all of the policy measures together, called combination. The final time spreads were then compiled into box plots. The plots for the variable *ratio of with the curriculum to total* is depicted in figure 7. This was used as it best highlights the state of school after the policy measures have been implemented. These plots are specific to the archetypal schools described in tables 3 and 4.

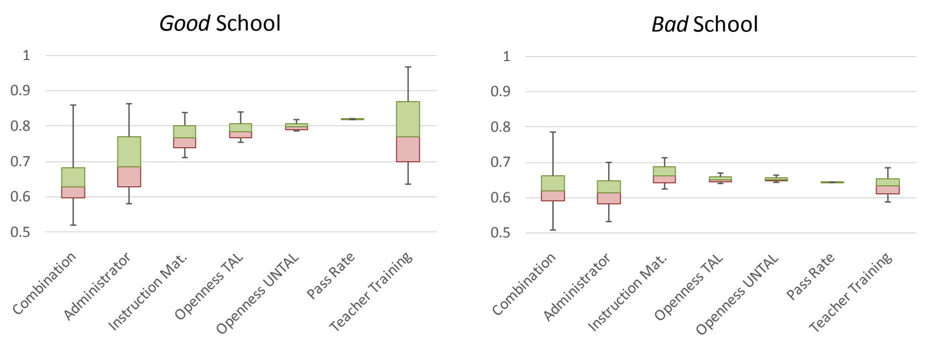

Figure 7: Box Plots of the Variable *Ratio of with the curriculum to total* for End Values of Sensitivity Analysis of Policy Measures

In the *good* school, it can be seen that teacher training has the biggest impact on increasing the ratio of *with* students, even greater than if all *policy measures* are enacted. In the *bad* school, the combination of factors is much more effective. The large spread, however, shows that it may not necessarily lead to the best results; thus, the exact combinations that lead to better results versus worse results need to be investigated further. Unlike the *good* school, the *bad* school seems to be less affected by teacher training, which could be a result of too many factors holding back teachers from enacting change.

5 Conclusions

To conclude, the original research question is considered. *Which parameters that we can influence effect whether students perform with the curriculum or fall behind?* Table 7 lists recommendations to accomplish specific goals for both *good* and *bad* schools. These recommendations are drawn from the sensitivity analysis conducted in section 4. The recommendations show repetitiveness as they are drawn from one type of archetypal school. Thus, the importance of school specificity is highlighted.

Table 7: Policy Recommendations for *Good* and *Bad* Schools

GOAL	RECOMMENDATIONS
Reduce the number of students that are behind the curriculum when completing elementary school	*Good*: More supportive administrator and increase of teacher training *Bad*: More supportive administrator, increase of teacher training, and a stricter pass rate for students that are behind
Increase number of students who are with the curriculum when completing elementary school	*Good*: Increase teacher training and make sure the administrator stays supportive *Bad*: More supportive administrator, increase teacher training and instruction materials
Reaching a higher ratio of with to behind students	*Good*: Increase teacher training and make sure the administrator stays supportive *Bad*: More supportive administrator, increase teacher training and instruction materials
Improving school reputation	*Good*: Increase teacher training and make sure the administrator stays supportive *Bad*: Make sure that the administrator stays supportive, then invest in instruction material

5.1 Future Work

Uncertainty analysis on the weighting factors should be conducted in future work. This would determine, for example, the weight of the influence of good teachers. Using this analysis, it could be determined which factors are more pertinent. Next, a scenario analysis on which combinations of factors lead to desired and undesired scenarios should be conducted. This analysis would highlight which combinations should be avoided most, as well as which combinations are the most desirable. This specifically applies to combination of policy measures analyzed in section 4.

As mentioned in section 1.1, the vision of this model is to create an online tool that administrators or other educational professionals can use to help them see how changes could affect their school. In future work, this system would be created. Additionally, future work of this study includes incorporating new research by the Bill and Melinda Gates Foundation on measuring effective teaching into the structure of the model [12].

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Appendix - Vensim Model Text View

```
following a class 1 year behind[grades 1 to 5,performance]=
    SUM(Students[grades 1 to 5, performance, state!]) *
        following a class time[next grades 1 to 5\
         ,performance] ~~|
following a class 1 year behind[g6,performance]=
    SUM(Students[g6, performance,state!]) * PULSE(TIME STEP
        +6,1)
    ~    student
    ~         |
following a class 1 year total=
    SUM(following a class 1 year[performance!])
    ~    student
    ~         |
following a class with curriculum[grades,performance]=
    (SUM(Students[grades, performance, state!])*following a
        class time[grades,performance\
         ])
    ~    student
    ~         |
following a class 1 year[performance]=
    SUM(following a class 1 year behind[grades!,performance
        ])
    ~    student
    ~         |
teacher enthusiasm=
    MIN(MAX(SMOOTH3((instruction material ratio * influence
        of instruction material on teacher enthusiasm\
    + teacher training * influence of teacher training on
        teacher enthusiasm
    + MIN((desired student teacher ratio/student teacher
        ratio)^7,1) * influence of student teacher ratio on
        teacher enthusiasm
    + scaled student improvement * influence of student
        improvement on teacher enthusiasm
    + school reputation * influence of school reputation on
        teacher enthusiasm)
    / (0.8*(influence of instruction material on teacher
        enthusiasm + influence of teacher training on teacher
         enthusiasm\
```

```
        +
     influence of student improvement on teacher enthusiasm
        + influence of school reputation on teacher
        enthusiasm\
        )) * MAX(MIN
    (administrator,1),0)
    , teacher adaption delay) ,0),1)
    ~     Dmnl
    ~     smoothed to prevent the spikes at the end of the
       academic year
    |
fraction of students passing[With]=
    1 ~~|
fraction of students passing[behind]=
    0.97
    ~     Dmnl
    ~     Good School 1;0.97;
        Bad School  1,0.97;
    |
total training effectiveness[teacher type, talented, career
   stage]=
    teacher openness to training TALENTED * teacher training
        * MAX(MIN(administrator,1),\
        0) ~~|
total training effectiveness[teacher type, untalented,
   career stage]=
    teacher openness to training UNTALENTED * teacher
       training * MAX(MIN(administrator,1\
        ),0)
    ~     Dmnl
    ~         |
teacher openness to training UNTALENTED=
    0.7
    ~     Dmnl
    ~     Good School 0.7
        Bad School  0.2
    |
instruction material effectiveness= WITH LOOKUP (
    teacher training*MAX(MIN(administrator,1),0),
        ([(0,0)-(5,1)],(0,0.3),(0.1,0.35),(0.189602,0.5)
           ,(0.348624,0.7),(0.648318,0.9),(1,1\
        ),(5,1) ))
    ~     Dmnl
    ~     instruction material will only be effective if it
       is used with training. \
        Hence, this lookup shows that after some training (a
```

```
            certain threshold \
        must be met) training makes the instruction
           materials really useful.
    |
difference between envisioned and current student level[
   grades,performance,state]=
    DELAY3I((envisioned with and behind fraction[performance
       ] * SUM(Students[grades,performance\
        !,state]) - Students[grades,performance,state]) /
           survey period of a year, learning delay\
        , initial learning difference)
    ~     student/year
    ~         |
students passing the grade[grades,performance,state] :EXCEPT
   :        [g6,performance,state\
        ]=
    Students[grades,performance,state]*fraction of students
       passing[performance]*outflow moment\
        /TIME STEP
    ~     student/year
    ~         |
following a class with total=
    SUM(following a class with[performance!])
    ~     student
    ~         |
following a class time[g1,performance]=
    PULSE(TIME STEP, 1 ) ~~|
following a class time[g2,performance]=
    PULSE(TIME STEP+1, 1) ~~|
following a class time[g3,performance]=
    PULSE(TIME STEP+2, 1) ~~|
following a class time[g4,performance]=
    PULSE(TIME STEP+3, 1) ~~|
following a class time[g5,performance]=
    PULSE(TIME STEP+4, 1) ~~|
following a class time[g6,performance]=
    PULSE(TIME STEP+5,1)
    ~     Dmnl
    ~         |
following a class with[performance]=
    SUM(following a class with curriculum[grades!,
       performance])
    ~     student
    ~         |
next grades 1 to 5:
    g2, g3, g4, g5, g6 -> grades 1 to 5
```

```
    ~
    ~         |
grades 1 to 5:
    g1, g2, g3, g4, g5
    ~
    ~         |
teacher type:
    good, average, unmotivated
    ~
    ~         |
student inflow[grades,With,state]=
    inflow rate[grades,state] * school reputation * inflow
       moment /TIME STEP ~~|
student inflow[grades,behind,state]=
    inflow rate[grades,state] * (1-school reputation) *
       inflow moment /TIME STEP
    ~     student/year
    ~         |
scaled student improvement= WITH LOOKUP (
    actual student improvement,
        ([(-1,0)-(1,1)],(-1,0),(-0.1,0),(-0.06,0.1)
            ,(-0.02,0.3),(0,0.5),(0.02,0.7),(0.06,0.9\
        ),(0.1,1),(1,1) ))
    ~     Dmnl
    ~         |
initial learning difference=
    0
    ~     student/year
    ~         |
reputation delay=
    2
    ~     year
    ~         |
teacher adaption delay=
    0.5
    ~     year
    ~         |
survey period of a year=
    1
    ~     year
    ~         |
influence of instruction material on teacher enthusiasm=
    0.2
    ~     Dmnl
    ~         |
influence of school reputation on teacher enthusiasm=
```

```
    0.2
    ~      Dmnl
    ~           |
influence of student improvement on teacher enthusiasm=
    0.5
    ~      Dmnl
    ~           |
influence of teacher enthusiasm on effective teaching=
    0.4
    ~      Dmnl
    ~           |
influence of teacher training on teacher enthusiasm=
    0.45
    ~      Dmnl
    ~           |
influence of good teachers on effective teaching=
    0.5
    ~      Dmnl
    ~           |
influence of instruction material on effective teaching=
    0.2
    ~      Dmnl
    ~           |
influence of student teacher ratio on teacher enthusiasm=
    0.2
    ~      Dmnl
    ~           |
total students passing the grade[g1]=
    SUM(students passing the grade[g1,performance!,state!])*
       TIME STEP ~~|
total students passing the grade[grades 2 to 5]=
    SUM(students passing the grade[grades 2 to 5,performance
       !,state!])*TIME STEP
    ~      student
    ~           |
total students completed[performance]=
    SUM(Total Completed[performance, state!])
    ~      student
    ~           |
envisioned fraction of unmotivated teachers[teacher type,
   ability,career stage]= WITH LOOKUP\
         (
    teacher enthusiasm,
        ([(0,0)-(1,1)],(0,0.8),(0.25,0.5),(0.5,0.3)
           ,(0.75,0.13),(1,0) ))
    ~      Dmnl
```

```
    ~           |
average and unmotivated:
    average, unmotivated
    ~
    ~           |
good and average:
    good, average
    ~
    ~           |
good teacher ratio=
    SUM(teachers[good,ability!,career stage!])/SUM(teachers[
       teacher type!,ability!,career stage\
        !])
    ~     Dmnl
    ~           |
completion of elementary school[performance,state]=
    Students[g6,performance,state]*completion fraction[
       performance]*outflow moment/TIME STEP
    ~     student/year
    ~           |
difference between envisioned and current teacher level[good
   , ability , career stage]=
    DELAY3((envisioned fraction of good teachers[good,
       ability,career stage] * SUM(teachers\
        [teacher type!, ability, career stage]) - teachers[
           good, ability, career stage]) / \
        survey period of a year, teacher development delay)
           ~~|
difference between envisioned and current teacher level[
   average,ability,career stage]\
        =
    DELAY3(((1 - envisioned fraction of unmotivated teachers
       [average,ability,career stage\
        ]) * (1 - envisioned fraction of good teachers[
           average,ability,career stage]) * SUM\
        (teachers[teacher type!, ability, career stage]) -
           teachers[average, ability, career stage\
        ]) / survey period of a year, teacher development
           delay) ~~|
difference between envisioned and current teacher level[
   unmotivated,ability,career stage\
        ]=
    DELAY3((envisioned fraction of unmotivated teachers[
       unmotivated,ability,career stage\
        ] * (1 - envisioned fraction of good teachers[
           average,ability,career stage]) * SUM(\
```

```
        teachers[teacher type!, ability, career stage]) -
           teachers[unmotivated, ability, career stage\
        ]) / survey period of a year, teacher development
           delay)
    ~     teacher/year
    ~     (eq 1) : good <-> avg + unmotiv teachers via
       training
        (eq 2 and 3) : unmotiv <-> avg teacher via teacher
           enthusiasm
    |
envisioned fraction of good teachers[teacher type,ability,
   career stage]= WITH LOOKUP \
        (
    total training effectiveness[teacher type,ability,career
        stage],
        ([(0,0)-(1,1)],(0,0),(0.2,0.08),(0.4,0.2),(0.6,0.4)
           ,(0.8,0.65),(1,1) ))
    ~     Dmnl
    ~         |
Cumulative teachers that have left[teacher type, ability,
   career stage]= INTEG (
    teachers leaving[teacher type,ability,career stage],
        0)
    ~     teacher
    ~         |
teacher enthusiasm effect on leaving= WITH LOOKUP (
    teacher enthusiasm,
        ([(0,0)-(5,1)],(0,0.5),(0.1,0.3),(0.2,0.22)
           ,(0.4,0.1),(0.6,0.04),(0.8,0),(3,0) ))
    ~     Dmnl
    ~         |
teachers leaving[teacher type, ability, fixed]=
    0 ~~|
teachers leaving[unmotivated, ability, mobile]=
    teacher enthusiasm effect on leaving * teachers[
       unmotivated, ability, mobile] * outflow moment\
         / TIME STEP ~~|
teachers leaving[average, ability, mobile]=
    (MAX(teacher enthusiasm effect on leaving, 0)) *
       teachers[average, ability, mobile] \
        * outflow moment/TIME STEP ~~|
teachers leaving[good, talented, mobile]=
    MIN(MAX(teacher enthusiasm effect on leaving + outside
       job opportunties, 0),1) * teachers\
        [good, talented, mobile] * outflow moment/TIME STEP
           ~~|
```

```
teachers leaving[good, untalented, mobile]=
    (MAX(teacher enthusiasm effect on leaving, 0)) *
       teachers[good, untalented, mobile] \
        * outflow moment/TIME STEP
    ~     teacher/year
    ~     (eq 1) all fixed teachers stay
        a frac related to the teacher improvement, teacher
           enthusiasm and job \
        opportunities elsewhere
    |
envisioned percentage of students with the curriculum= WITH
   LOOKUP (
    effective teaching,
        ([(0,0)-(1,1)],(0,0.3),(0.1,0.45),(0.25,0.56)
           ,(0.5,0.65),(0.75,0.79),(0.9,0.9),(1,1\
        ) ))
    ~     Dmnl
    ~         |
necessary instruction material per student=
    1
    ~     Dmnl
    ~         |
teacher development delay=
    1
    ~     year
    ~         |
teacher openness to training TALENTED=
    0.9
    ~     Dmnl
    ~     Good School 0.9
        Bad School  0.5
    |
instruction material ratio=
    instruction material per student/necessary instruction
       material per student
    ~     Dmnl
    ~         |
effective teaching=
    MAX(0,MIN(1,(instruction material ratio * instruction
       material effectiveness * influence of instruction
       material on effective teaching\
    + good teacher ratio * influence of good teachers on
       effective teaching
    + teacher enthusiasm * influence of teacher enthusiasm
       on effective teaching)
    / (0.8*(influence of instruction material on effective
```

```
        teaching + influence of good teachers on effective
        teaching\
          + influence of teacher enthusiasm on effective
             teaching ))))
    ~     Dmnl
    ~     total training effectiveness is already treated in
        the improvement of \
         average teacher -> good teachers. good teacher ratio
             is already effected \
         by the administrator through the training, however,
            how effective these \
         good teachers can be is still effected by the
            administrator, hence the \
         effect is mult. again here.
    |
total teachers=
    IF THEN ELSE(SUM(teachers[teacher type!,ability!,career
        stage!])>0, SUM(teachers[teacher type\
         !,ability!,career stage!]), 1)
    ~     teacher
    ~         |
teachers[teacher type,ability,career stage]= INTEG (
    hiring teachers[teacher type,ability,career stage] +
        difference between envisioned and current teacher
        level\
         [teacher type,ability,career stage] - teachers
            leaving[teacher type,ability,career stage\
         ],
         initial teachers[teacher type, ability, career stage
            ])
    ~     teacher
    ~         |
ability:
    talented, untalented
    ~
    ~         |
actual student improvement=
    SUM(difference between envisioned and current student
        level[grades!,With,state!])/total students\
         *survey period of a year
    ~     Dmnl
    ~         |
career stage:
    mobile, fixed
    ~
    ~         |
```

```
outside job opportunties=
    0.05
    ~     Dmnl
    ~     0 to 1
          0 -> no outside opportunities
          1 -> very many outside opportunities
    |

teacher gap=
    -total teachers+desired teachers
    ~     teacher
    ~         |
fraction teachers leaving=
    SUM(teachers leaving[teacher type!, ability!, career
        stage!]) / total teachers * survey period of a year
    ~     Dmnl
    ~         |
hiring teachers[teacher type, ability, mobile]=
    inflow moment/TIME STEP*MAX(0, teacher gap)*teacher
        market[teacher type, ability] ~~|
hiring teachers[teacher type,ability,fixed]=
    0
    ~     teacher/year
    ~         |
school reputation=
    DELAY3I(MIN(0.3 + 0.8*(ratio of with the curriculum to
        total - 0.2*MAX(0,(1-2*fraction teachers leaving\
          ))),1),reputation delay,initial school reputation)
    ~     Dmnl
    ~     base school reputation is set at .3
    |
initial teachers[teacher type, ability, fixed]=
    0.2*teacher market[teacher type, ability]*total students
        /desired student teacher ratio\
          ~~|
initial teachers[teacher type, ability, mobile]=
    0.8*teacher market[teacher type, ability]*total students
        /desired student teacher ratio
    ~     teacher
    ~     assume only 20% of teachers are intitially "fixed"
    |
teacher market[teacher type, ability]=
    0.29,0.01;
    0.4,0.2;
    0.01,0.09;
    ~     Dmnl
```

```
    ~     Good School 0.29,0.01;0.40,0.20;0.01,0.09;
        Bad School  0.14,0.01;0.35,0.35;0.01,0.14;
    |
extra teachers per student behind or challenged=
    0.05
    ~     teacher/student
    ~     Good School 0.05;
        Bad School  0.00;
    |
initial school reputation=
    0.8
    ~     Dmnl
    ~     Good School 0.8
        Bad School  0.5
    |
previous grades 2 to 5:
    g1,g2,g3,g4 -> grades 2 to 5
    ~
    ~         |
inflow moment=
    PULSE TRAIN(TIME STEP, TIME STEP, 1, FINAL TIME)
    ~     Dmnl
    ~     12 yr PULSE TRAIN(TIME STEP, TIME STEP, 1, FINAL
      TIME)
        1 yr  PULSE(TIME STEP, TIME STEP)
    |
grades 2 to 5:
    g2, g3, g4, g5
    ~
    ~         |
inflow rate[grades,normal]=
    92,0,0,0,0,0  ~~|
inflow rate[grades,challenged]=
    8,0,0,0,0,0
    ~     student
    ~     Good School [normal] 92,0,0,0,0,0; [challenged]
      8,0,0,0,0,0;
        Bad School  [normal] 92,0,0,0,0,0; [challenged]
          8,0,0,0,0,0;
    |
initial Students[grades,performance,normal]=
    85,10;
    85,10;
    85,10;
    85,10;
    85,10;
```

```
    85,10;  ~~|
initial Students[grades,performance,challenged]=
    3,2;
    3,2;
    3,2;
    3,2;
    3,2;
    3,2;
    ~     student
    ~     Good School 85,10; 3,2;
          Bad School   64,28; 1,7;
    |
completion fraction[performance]=
    1,0.97
    ~     Dmnl
    ~     Good School 1,0.97;
          Bad School   1,0.97
    |
Cumulative Dropouts[performance,state]= INTEG (
    SUM(dropout[grades!,performance,state]),
          0)
    ~     student
    ~           |
grades:
    g1,g2,g3,g4,g5,g6
    ~
    ~           |
outflow moment=
    PULSE TRAIN(0, TIME STEP, 1 , FINAL TIME)
    ~     Dmnl
    ~           |
dropout fraction per year[grades,performance]=
    0,0;
    0,0;
    0,0;
    0,0;
    0,0;
    0,0;
    ~     1/year/year
    ~     Good School 0,0;
          Bad School   0,0.03;
    |
Students[grades 2 to 5,performance,state]= INTEG (
    students passing the grade[previous grades 2 to 5,
       performance,state] + student inflow\
         [grades 2 to 5,performance,state] - dropout[grades 2
```

```
         to 5,performance,state] - students passing the
            grade\
         [grades 2 to 5,performance,state] + difference
            between envisioned and current student level\
         [grades 2 to 5,performance,state],
         initial Students[grades 2 to 5,performance,state])
            ~~|
Students[g1,performance,state]= INTEG (
    student inflow[g1,performance,state] - dropout[g1,
       performance,state] - students passing the grade\
         [g1,performance,state] + difference between
            envisioned and current student level[g1\
         ,performance,state],
         initial Students[g1,performance,state]) ~~|
Students[g6,performance,state]= INTEG (
    students passing the grade[g5,performance,state] +
       student inflow[g6,performance,state\
         ] - dropout[g6,performance,state] - completion of
            elementary school[performance,state\
         ] + difference between envisioned and current
            student level[g6,performance,state],
         initial Students[g6,performance,state])
    ~    student
    ~        |
dropout[grades,performance,state]=
    dropout fraction per year[grades,performance]*Students[
       grades,performance,state]*TIME STEP
    ~    student/year
    ~        |
Total Completed[performance,state]= INTEG (
    completion of elementary school[performance,state],
        0)
    ~    student
    ~        |
learning delay=
    0.1
    ~    year
    ~        |
envisioned with and behind fraction[With]=
    envisioned percentage of students with the curriculum
       ~~|
envisioned with and behind fraction[behind]=
    1-envisioned percentage of students with the curriculum
    ~    Dmnl
    ~        |
performance:
```

```
    With, behind
    ~
    ~           |
state:
    normal, challenged
    ~
    ~           |
total students=
    IF THEN ELSE(SUM(Students[grades!,performance!,state!])
       >0, SUM(Students[grades!,performance\
        !,state!]), 1)
    ~      student
    ~           |
ratio of with the curriculum to total=
    SUM(Students[grades!, With, state!])/total students
    ~      Dmnl
    ~           |
student teacher ratio=
    total students/total teachers
    ~      student/teacher
    ~           |
desired teachers=
    SMOOTH3(total students/desired student teacher ratio + (
       SUM(Students[grades!, behind\
        , state!]) + SUM(Students[grades!, performance!,
           challenged])) * extra teachers per student behind
            or challenged\
        , teacher adaption delay)
    ~      teacher
    ~      smoothed to prevent spikes in delay during end of
       academic year
    |
administrator=
    0.9
    ~      Dmnl
    ~      Good School 0.9
         Bad School  0.8
    |
desired student teacher ratio=
    25
    ~      student/teacher
    ~      Bood School 25;
         Bad School  30;
    |
instruction material per student=
    0.9
```

```
    ~      Dmnl
    ~      Good School 0.9
          Bad School   0.5
    |
teacher training=
    0.7
    ~      Dmnl
    ~      Good School 0.7
          Bad School   0.7
    |
*******************************************************
    .Control
*******************************************************~
          Simulation Control Parameters
    |
FINAL TIME  = 12
    ~      year
    ~      The final time for the simulation.
    |
INITIAL TIME  = 0
    ~      year
    ~      The initial time for the simulation.
    |
SAVEPER  =
          TIME STEP
    ~      year [0,?]
    ~      The frequency with which output is stored.
    |
TIME STEP  = 0.03125
    ~      year [0,?]
    ~      The time step for the simulation.
    |
```