Modeling Framework for Understanding the Dynamics of Learning Performance in Education Systems

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Abstract

Both developing and developed countries allocate a substantial amount of their budgets to their education sectors in an attempt to improve the learning performance of the students at each stage in the education system. The stages in the system, generally, include Early Childhood Development (ECD), Elementary and Secondary (K-12), and Post Secondary Education (PSE). This paper illustrates that in designing effective policies to improve learning performance, it is important to understand how stages in the education system interact over time. This paper presents a modeling framework that can be used to evaluate the implications of success in one stage to other stages of the education system. This research helps in understanding "where and why" to focus education system reform efforts in order to improve the performance of the students throughout all stages of the education system.

Keywords: Education, high school dropouts, early childhood development, parents, knowledge.

Introduction

It has been widely recognized that education provides one of the best chances to improve economic security, job satisfaction, quality of life, and ability to enjoy a healthy lifestyle (Poveda 1999). Both developing and developed countries allocate a substantial amount of their budgets to their education sectors in an attempt to improve education attainment of the individuals. Education attainment takes place within a continuum process that involves learning through different stages over an individual's life span. These stages are typically conceived as being: Early Childhood Development (ECD), Elementary to Secondary School (K12), Post Secondary Education (PSE), and Adult Education and Skills Development. There are a variety of unique issues associated with each of these stages. For example, problems at the ECD stage may include low cognitive and social skills development, or poor motor skills. Low graduation rates, high dropouts rates, and high retention rates (i.e., holding students back) can be matters of concern in the K12 stage. At the later stages of the continuum, the problem may be low PSE enrollment rates, and low skills development.

The magnitude of these problems at any point in time may varies in different countries. However, in designing effective policies to improve learning performance, it is important to recognize that the problems experienced in these stages are nonlinearly interconnected to each other. Problems created in early stages of the education system can generate or intensify problems in the later stages. For example, poor developmental foundations such as culture, education, and health established at ECD stage could create barriers in learning at high school, which may in turn lead to higher unemployment and lower income levels when the children become adults. When such adults become parents, their children will likely face more challenging learning environments and greater obstacles to success as they progress through each stage of the education system.

Each stage of the learning continuum requires attention to address its unique problems, particularly when each stage is viewed as a separate, isolated component. However, in real life, the stages are not isolated. They are, in fact, elements of a single, interconnected, and integrated system in which problems relating to one stage are nonlinearly interconnected to problems in other stages.

Problems arising in early stages of the continuum, if not fixed, can generate or intensify problems in the later stages. For example, poor developmental foundations such as culture, education, and health established at ECD stage could create barriers to learning at high school, which may in turn lead to higher unemployment and lower income levels when the children become adults.

Similarly, problems at later stages of the continuum such as lower levels of parents' education attainment might create obstacles for their children to learn effectively in the ECD stage. On the other hand, performance at one stage has also implications for other stages. For example, physical, social and intellectual foundations developed at the ECD stage exert a powerful influence on later well-being of the individual, build coping abilities and competencies and help make children physically strong and emotionally healthy.

Given the fact that problems at early stages have implications for later stages and vice versa, the question is which stage does it make sense to focus on in order to enhance the education attainment of the individuals at a faster pace? Most research overwhelmingly confirms the importance of the ECD stage in shaping long-term learning outcomes. The ECD stage lays the developmental foundations in culture, education, and health, all of which influence how well children learn as they progress through later stages of the continuum system **(**Berman 1984, Walker 1991, Curie et al. 1995, Young 1996, and Donald 1997**)**. However, to design effective and robust strategies for establishing sound foundations for children at the EC stage, it is necessary to fully understand the structural impediments to the success of programs focused at the ECD stage. More specifically, in light of the interconnectedness of the education system, policy makers need to have an understanding of how addressing the problems of other stages could influence the likelihood and sustainability of success in the ECD stage. Furthermore, it is necessary to develop an appreciation of how problems of one stage may evolve over time and how those dynamics could create new challenges for the programs addressing problems in other stages.

Objective and scope of the model

This research involved development of a simulation model that integrates stages of the learning continuum into a one complete system. The model maps how different system elements and stages are interconnected to each other and helps in understanding how success/failure of programs at one stage evolve over time and influence success/failure of programs at other stages.

The model can be used to evaluate the potential overall impact of programs designed to improve the education attainment of Aboriginal people at specific stages of the learning continuum. For example, in order to increase the overall education attainment of Aboriginal people, what would be the relative leverage of a strategy that improves the performance of children at ECD stage by 20 or 40 % versus another strategy that directly focuses on improving the performance of students at K-12 stage by 20 or 40 % or another strategy that attempts to increase the PSE enrolment by 25 % or another strategy that assists K12 dropout students in increasing their performance by 30 %. The model will also allow testing combinations of these different strategies implemented at different times. The purpose of the model would be to understand what would be the potential overall outcomes of strategies if they succeed in fulfilling their (stage-specific objectives) by a certain percentage (e.g., 10, 20, 30, 40 etc).

Scope of the model

The model helps policy developers to understand "where and why" to focus more investment in the continuum in order to accelerate the rate at which education attainment of Aboriginal is enhanced. The scope of the model is broad in terms of tracking the students and their performance as they move through stages (ECD, K12, and PSE) in the continuum. The detail complexity has been purposely avoided in this iteration of the model in order to allow a focus dynamic performance of the education system as a whole, arising how the underlying structure of system. Important considerations such as family violence, gender, single parent family issues, that may in real life influence how students perform as they progress through each stage of the continuum are not included in the model. The impact of such factors is, however, implicitly represented in the model by an aggregate measure at each stage in the continuum.

The model also does not focus on investigating different methods (i.e., issues of program design) for achieving a certain degree of success under a strategy. For example, the learning performance of K12 students can be improved by different ways such as training and hiring of more Aboriginal teachers, Aboriginal control of education, and including courses on indigenous curriculum. The model does not directly incorporate structure that reflects each of these approaches. Consequently, the model in its current form cannot be used to investigate which of these ways would provide more leverage for improving learning outcomes for K12 students.

Model Overview

Figure 1 depicts the model overview that maps the flow of students and their "knowledge" through different stages of the education system. In this model, "knowledge" represents a collection of factors such as learning ability, learning capacity, and skills or other characteristics of an individual that help in progressing through different stages of the learning continuum. These stages are defined as: Early Childhood Development (ECD), Elementary and High School (K-12), K-12 Grads, K-12 Dropouts, Post Secondary Education (PSE), and parents. Students move through these stages of the education system and eventually become parents themselves. As shown in figure 1, four types of parents are considered in this model. These are: 1) K-12 dropout parents, 2) PSE dropout parents, 3) PSE Grads parents, and 4) K-12 Grads not enrolled in PSE. It is assumed that these four types of parents collectively establish an environment that influences the learning of students of new generations as they move through the ECD and K-12 stages. Students at the PSE stage mostly do not live with their parents; hence, it is assumed that parental influence on PSE students is insignificant.

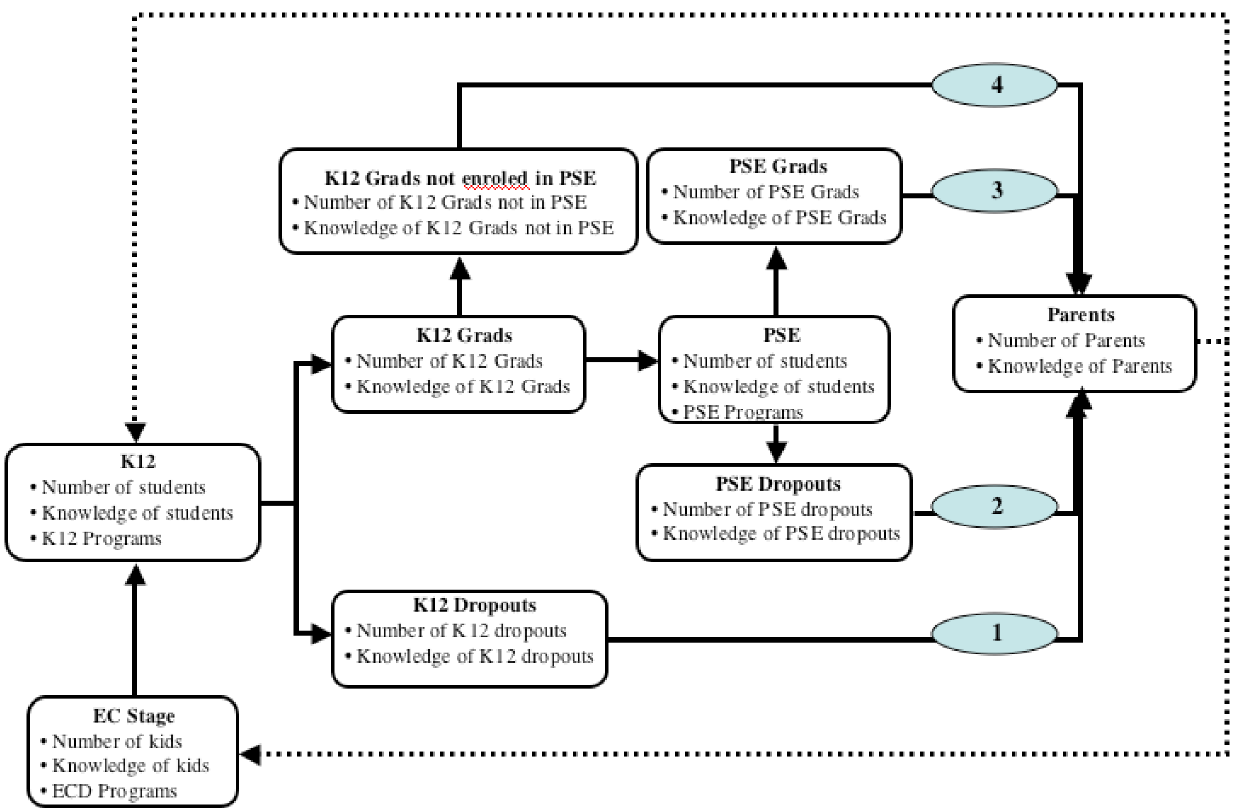

Figure 1 Model overview

As shown in Figure 1, the stages incorporated in the model are interconnected with each other, which allows the model to track both the movement of students as well as the knowledge that they gain at each stage. The model incorporates an assumption that the level of knowledge gained by students any stage depends on the level of knowledge transferred from previous stages plus the knowledge they gain at the "current" stage. It is, admittedly, difficult to precisely measure or even to quantify the amount of an individual's knowledge at each stage continuum. The focus of the model is on understanding the dynamic interaction between different factors that influence the rate of change in the knowledge of individuals over time. Precision in quantification of knowledge is not necessary given in this objective.

For simulation purposes, an index scale is utilized that represents an assumed initial average level of knowledge for individuals at each stage. For example, it is assumed that the average knowledge of children at the ECD stage is 10 Units; at the K12 stage the assumed average knowledge is 40 Units, the average knowledge of K12 graduates is 80 Units, while the average knowledge for K12 dropouts is 70 Units. The assumed differences in the initial level of knowledge for individuals at each stage of the education system is premised on the fact that, on average, the knowledge of individuals at any stage will be greater than the knowledge of individuals at preceding stages. For example, a PSE graduate has relatively more knowledge than a K12 graduate.

The model also incorporates structure and logic for establishment and discontinuation of ECD, K12, and PSE programs (as distinct from the ECD, K12 and PSE stages of the continuum). The model increases or decreases the number of these programs available to ECD, K12, and PSE students respectively, depending on the need of these programs based on the current number of individuals at these stages. For example, if the current number of individuals increases at a stage, the model adds incrementally more programs to that stage until the desired need of the programs is reached. The number of programs available to ECF, K12, and PSE students represent the "productive capacity" of the school system at each stage and is one factor that influences the rate at which individuals are able to add knowledge at that stage of the learning continuum.

Dynamic hypothesis of the model

Figure 2 illustrates the dynamics hypothesis of the modeling framework presented in this paper. This dynamic hypothesis describes the positive feedback processes of the education system that demonstrates the interconnections of the different stages. As shown in the figure, it is assumed that the level of knowledge at any stage depends on the level of knowledge transferred from previous stage plus the knowledge gained at that stage. The gain in knowledge for children at ECD and K-12 stages, however, can also be influenced by their parents' knowledge.

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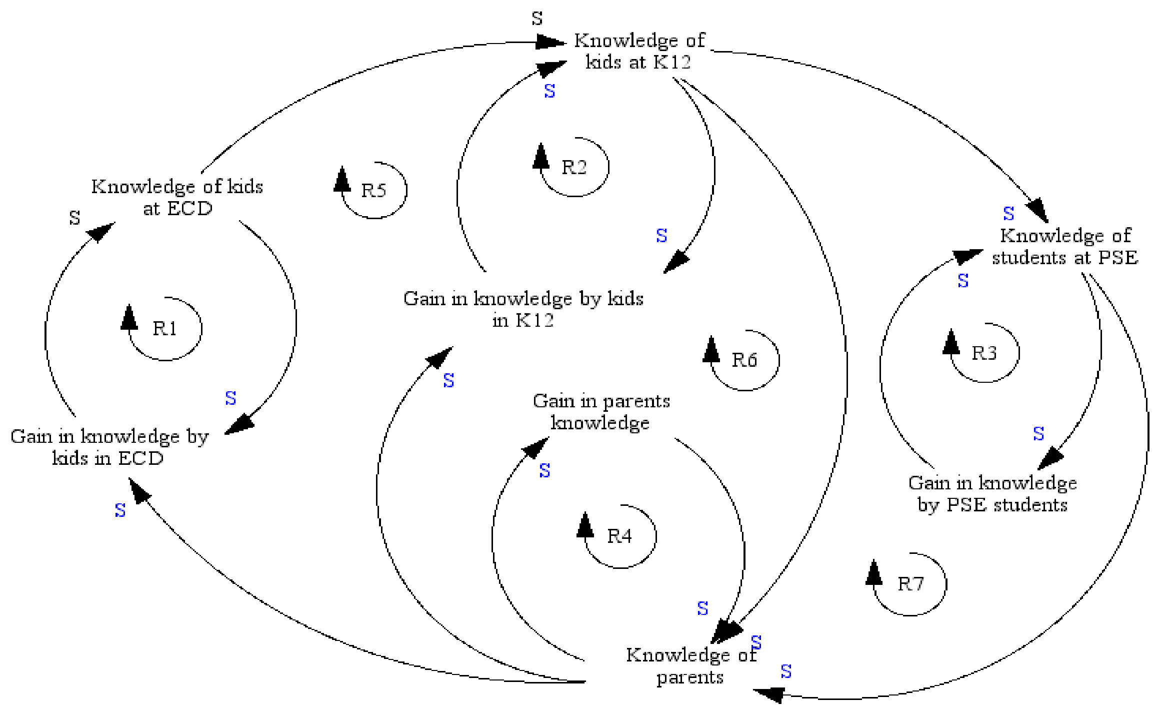

Figure 2 Dynamic hypothesis of the model

As shown in figure 2, the knowledge gained at each stage in the education process is determined by the relative strength of the positive feedback loop operating at that stage. The level of knowledge or learning that students acquire at earlier stages of the education system can affect their learning outcomes in later stages. Similarly, knowledge gained at later stages would influence the rate of gaining knowledge at early stages by students in succeeding generations. For example, learning at the ECD stage can affect the performance of students in elementary and high school. Low literacy level in high school can be a barrier to acquiring knowledge at the University and college level. Conversely, high literacy rates in PSE can increase the gain in knowledge at ECD and K-12 stages.

The relative strength of a positive feedback loop at a certain stage in figure 2 also depends on the number of individuals at that stage. Figure 3 shows the concept of the number of individuals to determine the average knowledge of an individual for only ECD and K-12 stages. Figure 4 repeats the same concept illustrated in figures 2 and 3 for all of the stages considered in this paper.

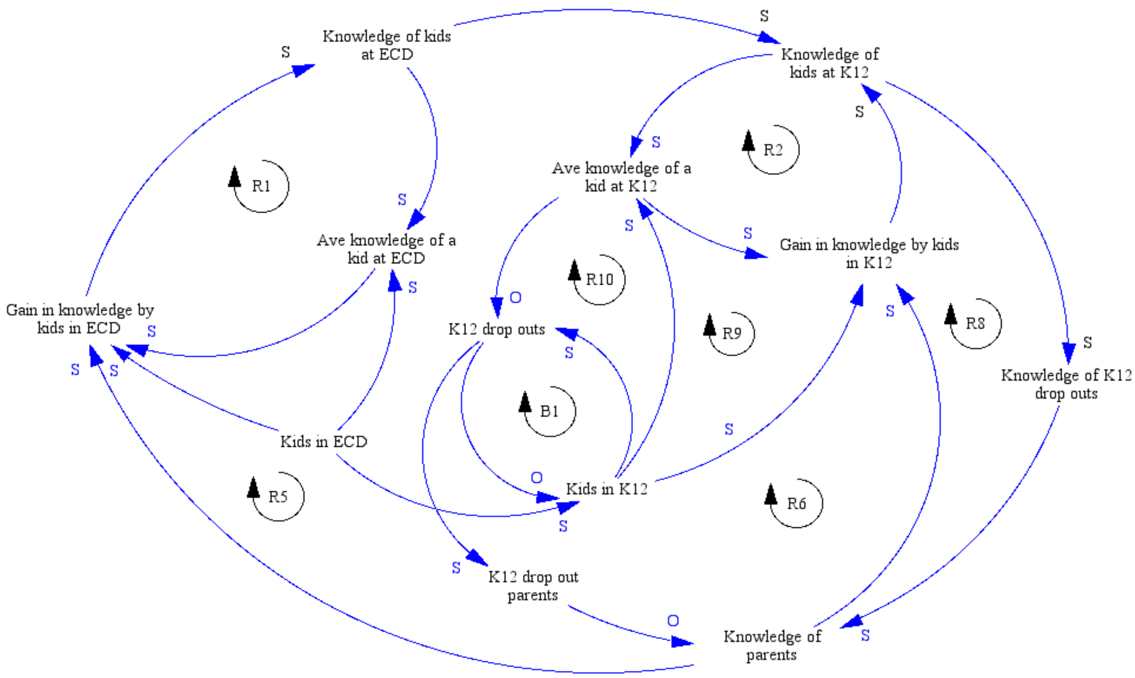

Figure 3 Model structure for ECD and K-12 stages

As shown in Figure 3, average knowledge of a child at the ECD stage depends on the number of children in ECD and total knowledge of all children at ECD. The average knowledge of a child at ECD, in turn, influences the rate at which knowledge is gained in ECD. In the case of the K-12 stage, the average knowledge of a child at K-12 not only influences the gain in knowledge at K-12 but also affects the dropout or graduation rate.

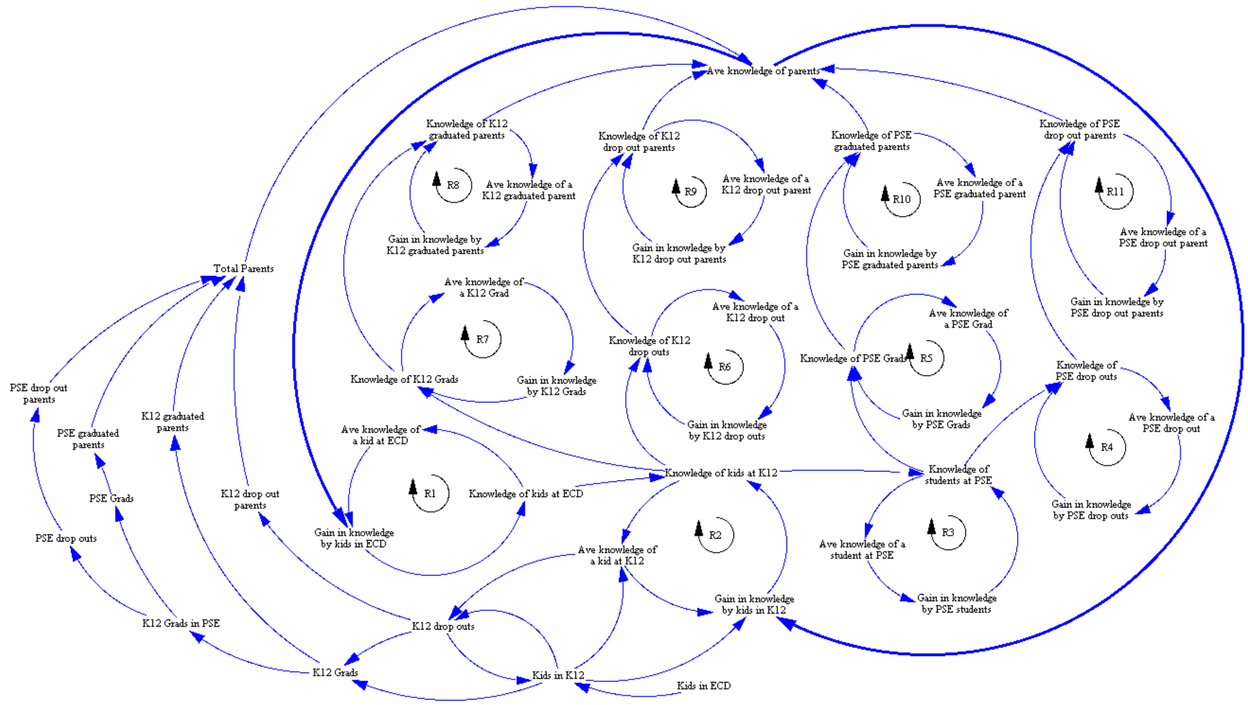

Figure 4 Structure of the model

Simulation Model

The structure of the model (Figure 4) is converted into a mathematical model using the System Dynamics methodology. Figures 5, 6, and 7 illustrate the stock-flow structure of the model. Figure 5 shows the flow of individuals through the various stages from ECD to parents while figure 6 tracks the flow of knowledge of those individuals as they move from one stage to another. For illustration purpose the interaction between individuals and their knowledge for K-12 stage is shown in Figure 7 and is discussed in this paper. The interaction between individuals and their knowledge for other stages is not depicted, but is the same as described for the K-12 stage.

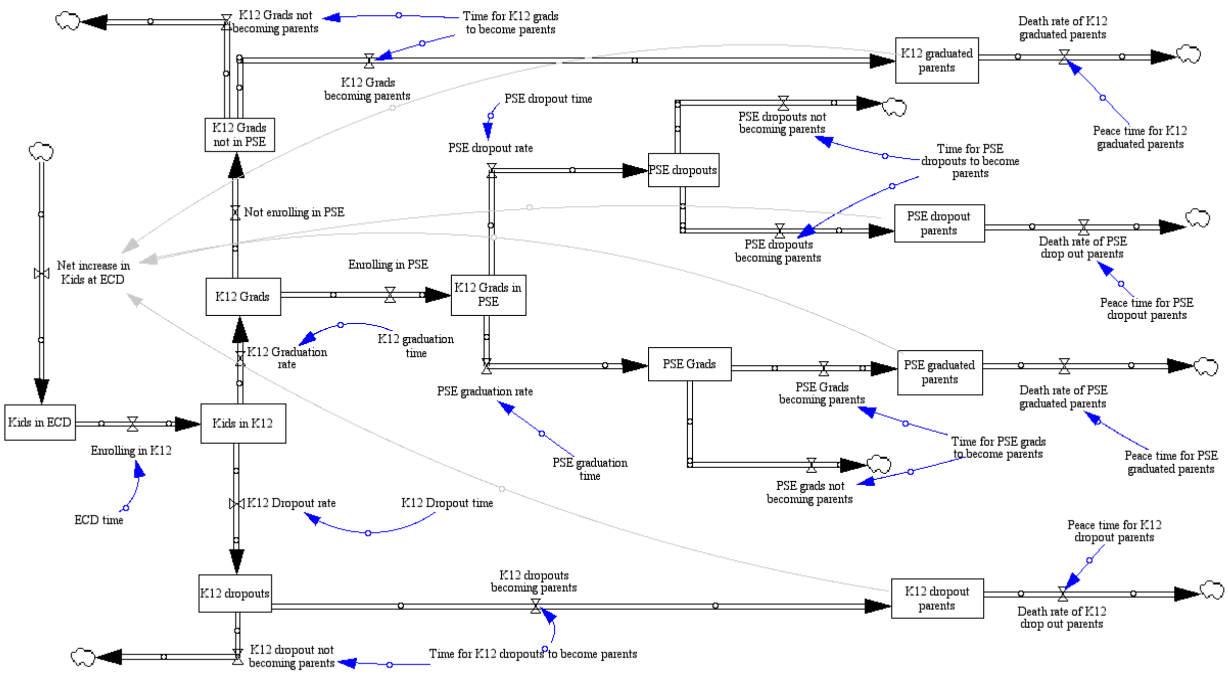

Figure 5 Flow of individuals through different stages

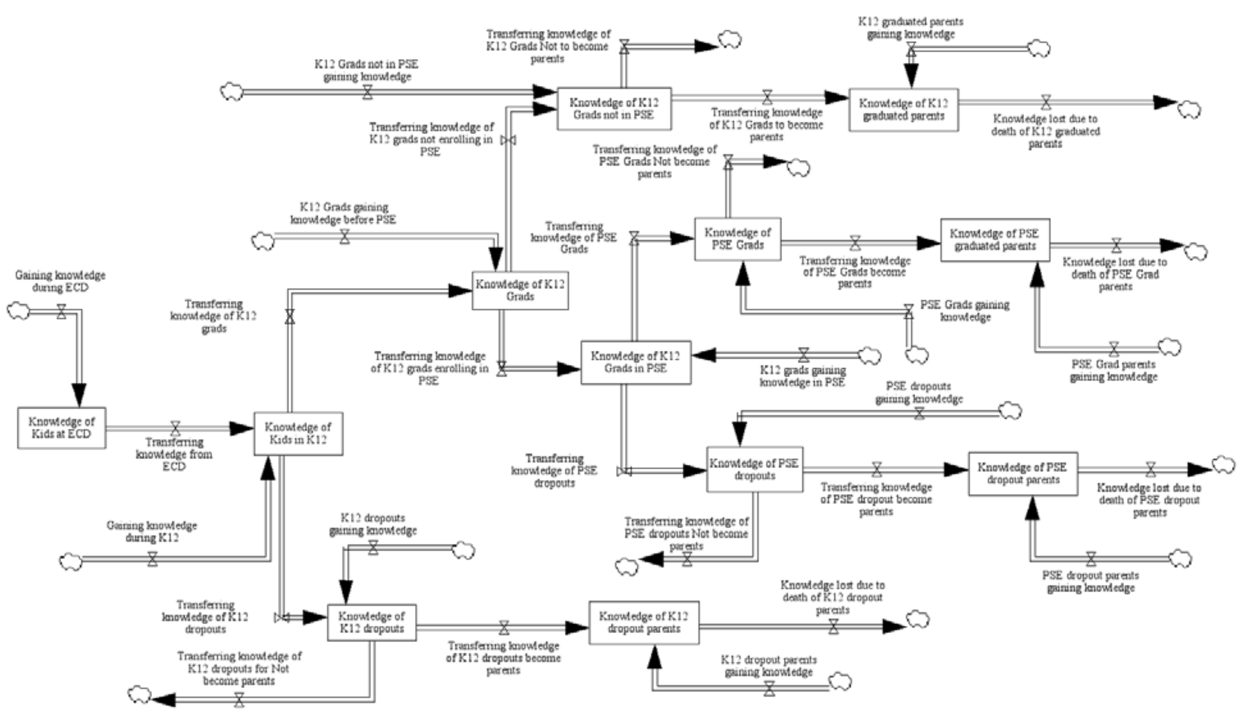

Figure 6 Flow of knowledge through different stages

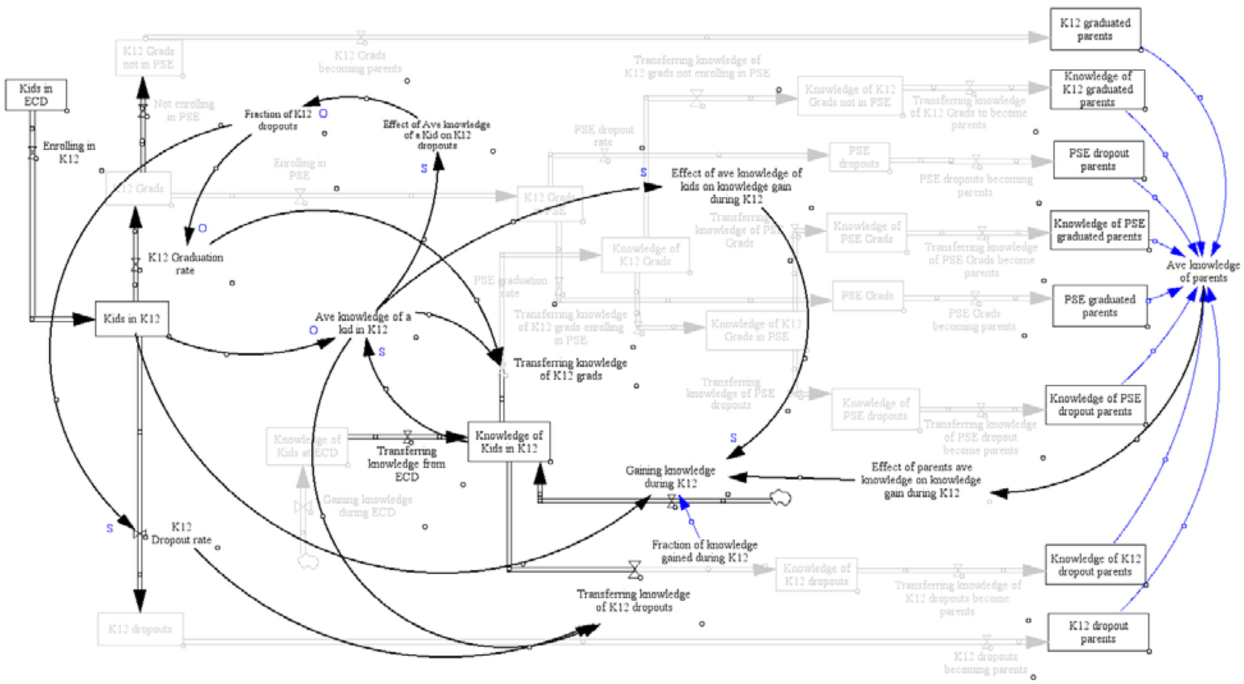

Figure 7 Interaction between children in K-12 and their knowledge

As shown in figure 7, children from the K-12 stock move to either the stock of K-12 dropouts or to the stock of K-12 graduates. The number of K-12 dropouts or graduates is assumed to vary every year based on the average knowledge of children enrolled in K-12. This relationship is defined as:

Fraction of K12 dropouts = *Normal fraction of K12 dropouts x Effect of Ave knowledge of kids on K12 dropout* (1)

Where

Fraction of K12 dropouts is assumed to vary from 0.02 to 0.45.
Normal fraction of K12 is assumed equal to 0.3.
Effect of Ave knowledge of kids on K12 dropout is an assumed nonlinear function of the *Ave knowledge of kids in K12*.

Figure 8 shows a hypothesized relationship based on author's heuristic understanding between *Ave knowledge of kids in K12* and *Effect of Ave knowledge of kids on K12 dropout.* The vertical axis in figure 8 represents the assumed values for *Effect of average knowledge of kids on K12 dropout* while the horizontal axis represents the normalized values of the *Ave knowledge of kids in K12*. As shown in figure 8, it is assumed that when *Ave knowledge of kids in K12* increases to more than one, then the *effect of average knowledge of kids on K12 dropout* will decrease, in turn, *Fraction of K12 dropout* will decrease. It is also assumed that when *Ave knowledge of kids in K12* decreases to less than one, the *Fraction of K12 dropouts* will also increase.

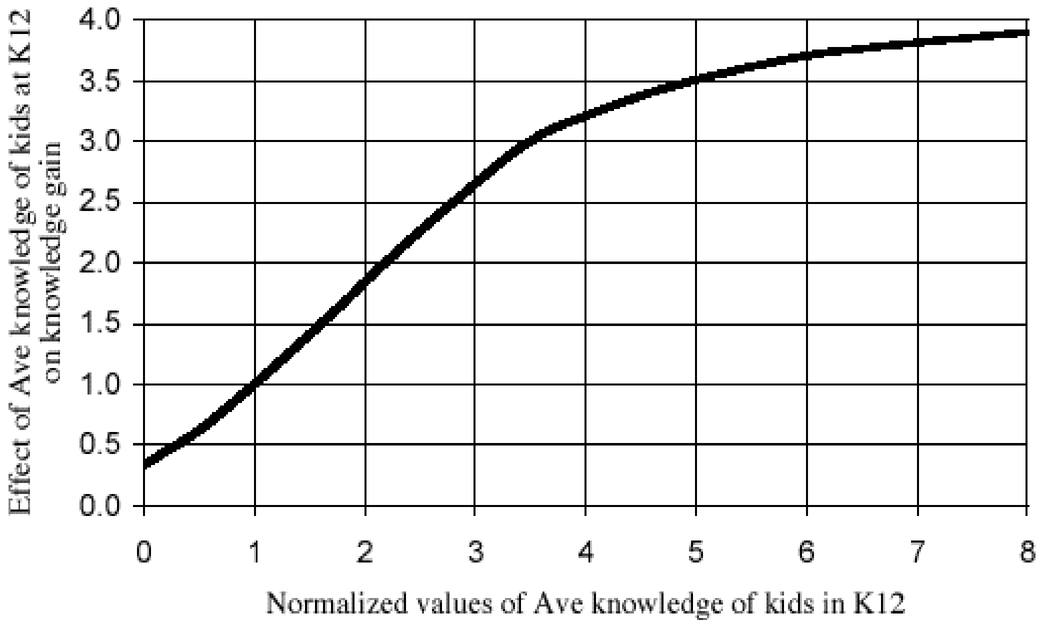

Figure 8 Heuristic relationship for effect of ave. knowledge of children on K-12 dropout.

The variable *Ave knowledge of kids in K12* depends on *Knowledge of kids in K12* and *Kids in K12*. The *Knowledge of kids in K12* increases by knowledge transferred from ECD and knowledge gained during K-12 stage, and decreases by knowledge transferred by K-12 dropouts and graduates.

It is assumed that a child gains a certain amount of knowledge at K-12 stage. This amount of knowledge endogenously varies by the average knowledge of parents and average knowledge of kids at K12. In the model, *Gaining knowledge during K12* is defined as:

Gaining knowledge during K12 = Fraction of knowledge gained during K12 x Kids in K12 x Effect of ave knowledge of kids on knowledge gain during K12 x Effect of parents ave knowledge on knowledge gain during K12

Where

Fraction of knowledge gained during K12 is an assumed value of knowledge that kids gain from school and home during K12 period.

Effect of ave knowledge of kids on knowledge gain during K12 and *Effect of parent's ave knowledge on knowledge gain during K12* both are assumed nonlinear functions of *Ave knowledge of kids in K12* and *Ave knowledge of parents* respectively. A similar shape is assumed for these functions, as shown in Figure 9.

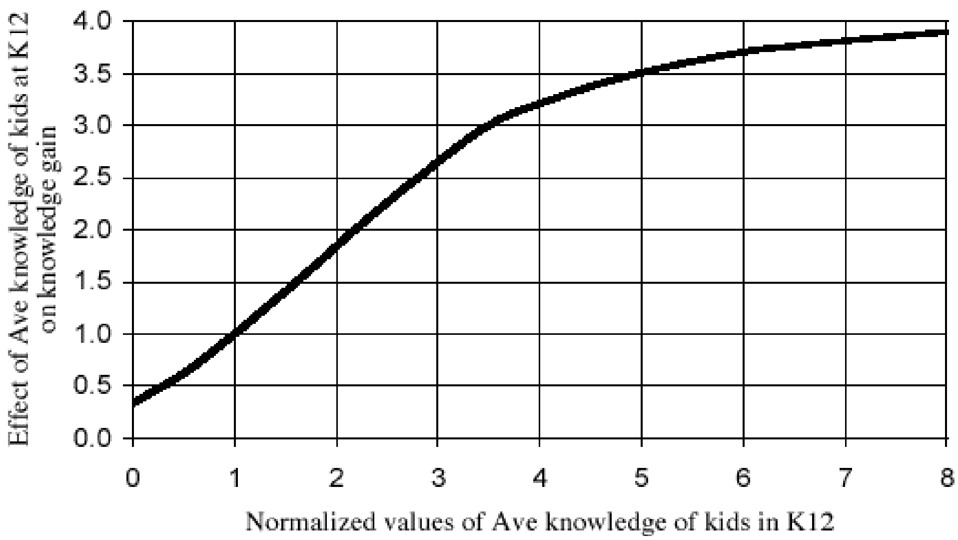

Figure 9 Heuristic relationship for effect of Ave knowledge of children at K-12 on knowledge gain

As shown in Figure 9, it is assumed that when *Ave knowledge of parents* increases to more than one, then its effect on the gain in knowledge by children in K-12 will also increase. On the other hand, when *Ave knowledge of parents* decreases to less than one, the gain in knowledge by children in K-12 will also decrease.

The process for gain in knowledge by individuals at other stages such as ECD and PSE is similar as described for the K-12 stage, however, the strength of the nonlinear relationships is considered to be different for each stage. For example, it is assumed that effect of parents' knowledge on knowledge gain at the ECD stage is stronger than at the K-12 stage because at ECD stage children are more dependent on their parents.

It is, admittedly, difficult to measure or quantify the amount of an individual's knowledge at each stage of the education process. However, the focus of this paper is on understanding the interaction between different factors that influence the rate of change in the knowledge of individuals over time. For simulation purpose, a scale is assumed that represents an initial level of the average knowledge of individuals at each stage. For example, it is assumed that the average knowledge of children at the ECD stage is 10 Units; at the K-12 stage the assumed average knowledge is 40 Units, the average knowledge of K-12 graduates is 80 Units, while the average for K-12 is 60 Units. The assumed differences in the initial level of knowledge for individuals at each stage of the education system is premised on the fact that, on average, the knowledge of individuals at any stage will be greater than the knowledge of individuals at preceding stages. For example, a PSE graduate has relatively more knowledge than a K12 graduate.

Simulation results

Base run

Initially the model is parameterized in a way that equilibrium exists in all stocks. To test the dynamic hypothesis articulated in this paper, the model is driven from equilibrium by an exogenous disturbance. The step input, a sudden one-shot disruption of the system's equilibrium state, is a very simple and uncomplicated, yet informative, disturbance (Lynies, 1988). Such a test is important for understanding any tendency internal to the system (Saeed, 1987). The equilibrium of the model is disturbed by a 20 percent step increase in the *Net increase in Kids at ECD* at time 10. All other parameters and nonlinear relationships remain unchanged. Figures 10 (a), (b), (c), and (d) show a base run simulation of the model over a hypothetical 300 year period starting in equilibrium at year one.

As a consequence of the step increase in the number of children at ECD, the number of individuals at all stages increases proportionally throughout the remainder of the simulation. For example, Figure 10 (a) and (b) show an increase in the number of *K12 dropout parents* and *PSE graduated parents* respectively. As the number of individuals at each stage increases, so does the knowledge of these individuals at that stage. The average knowledge of individuals at a stage captures the relative change in the number of individuals and their respective knowledge. For example, Figure 10 (c) shows variations in the *Ave knowledge of kids at ECD* that reflect the relative change in the number of *Kids in ECD* and *Knowledge of Kids at ECD*. Similarly, Figure 10 (d) reflects the changes in the total number of all types of parents considered in this paper and changes in total knowledge of these parents.

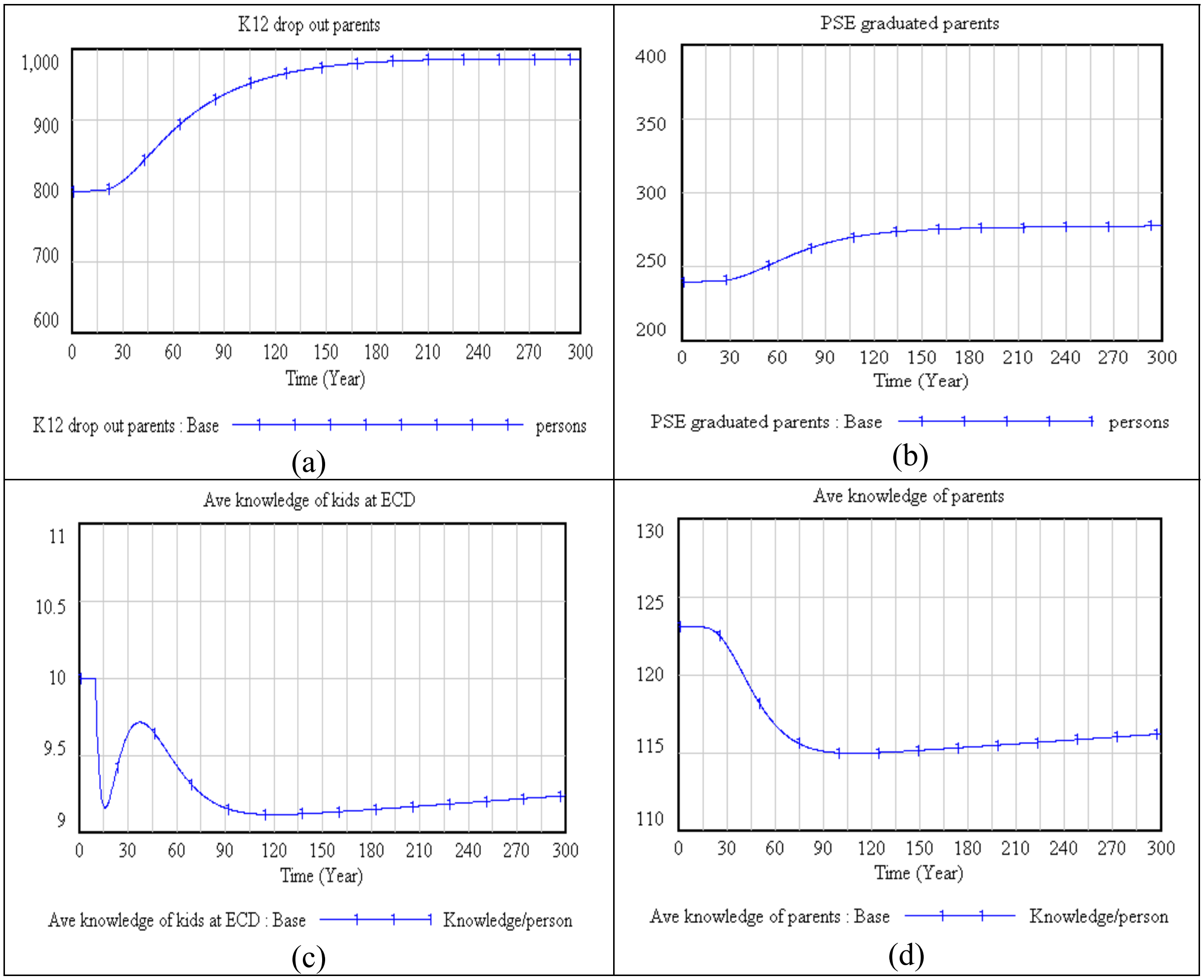

Figure 10 Simulation results of base runs

Policy runs

A number of policy experiments are carried out on the base run of the model to understand the implications of different strategies aimed at improving overall education attainment such as increasing the average knowledge of parents, reducing K-12 dropout rates, and increasing PSE graduates. This section describes four of these policy experiments, implemented at time 15 in the simulation. These policy experiments are:

1) Investment in ECD: making ECD programs more effective than its present situation is an effort to increase the gain of knowledge of children at the ECD stage. This policy is implemented by stepping up the normal increase in ECD programs. This would represent an additional improvements in the ECD programs including, for example, extending services and facilities at preschool daycare centers, hiring more qualified and experienced staff, and introducing new, more effective approaches to learning. Similarly, examples of external factors at elementary and secondary school (K-12) stage would include curriculum, qualification of teachers, and facilities provided at school.

2) Investment in K-12: improving the performance of high schools to increase the gain in knowledge by high school students. This policy is tested by stepping up the normal increase in K12 programs. This would represent an additional improvements including, for example, improving standard student to teacher ratios, improving methods of teaching, increasing teacher competency through training programs, and introducing modern technology in the K12 programs that would help students to gain more knowledge.
3) Investment in PSE: improving the performance of the Universities and colleges so as to increase the gain in knowledge by PSE students. This policy is implemented by stepping up the normal increase in PSE programs. For example, this policy could be implemented by hiring more qualified professors in Universities or by offering advanced technologies facilitate learning at the PSE level.
4) Increasing PSE Enrollment: This policy is implemented by stepping up the fraction of K-12 graduates that enroll in PSE. The stepping up of the PSE enrollment could be achieved by measures such as expanding the capacity at Universities and colleges or by offering scholarships to help support students involved in studies at the PSE stage.

These four policy experiments are conducted using typical goal-gap structure for the time period (0 to 500). The simulation results of these experiments are shown in Figure 11 (a), (b), (c), and (d).

As shown in figure 11 the policy run,"K12" which focuses on improving learning outcomes in high schools is relatively more effective as a strategy for improving the average knowledge of parents and reducing dropouts from K-12 and PSE stages of the education system. The K12 policy is more effective because of a cascading leverage effect within the education system. Strengthening the positive loop (R2) in figure 2 has the compounding effect of strengthening the other positive loops shown in figure 2. However, one can imply that increasing the strength of any loop in figure 2 would result in increasing the strength of all other loops. The question is on which loop should efforts be focused and why? The reasons why intervention focused on the K-12 stage is found to be more effective are: number of individuals at K-12 stage is relatively more than to the number of individuals at any stage, and the location of the K-12 stage in the system is such as to contribute relatively more in increasing the knowledge of parents for a longer period of time.

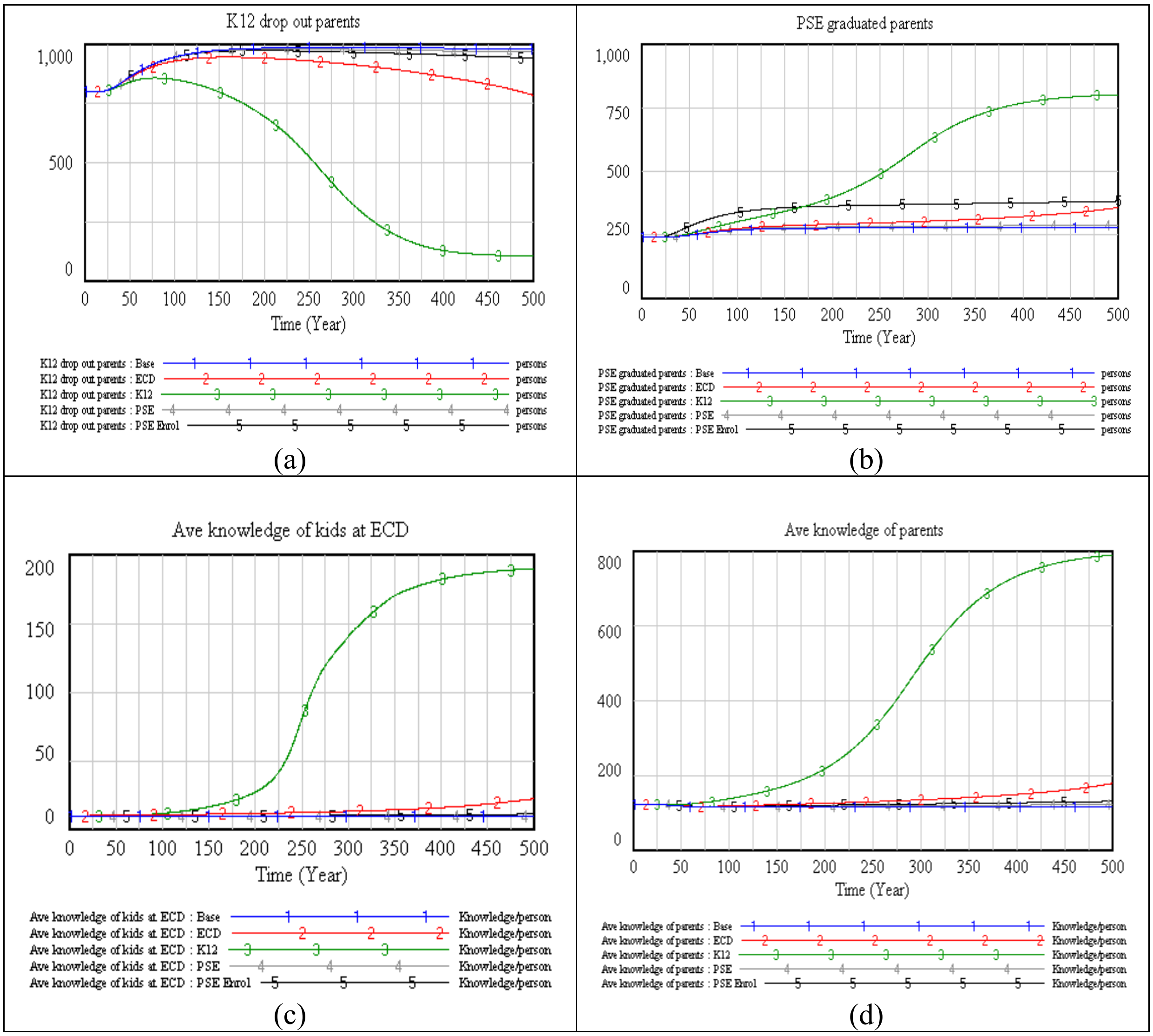

Figure 11 Simulation results of policy runs

Policy runs in the long run

In this section the same four policy experiments described above are repeated for an extended period of time (0 to 1000) to explore the long-term consequences of these four strategies. The simulation results of these experiments are shown in Figure 12 (a), (b), (c), and (d). As shown in figure 12, the strategy of making ECD programs more effective will, in the long term, produce education system performance outcomes that match the outcomes achieved under the “K12” strategy.

One of the reasons why the ECD-focused strategy takes a longer time than the K-12 strategy is the time lag involved in increasing the knowledge of parents. Children in K-12 influence the average knowledge of parents more quickly they become parents more quickly than children in the ECD stage. Once the knowledge level of parents begins to increase, the rate of knowledge gain at ECD and K-12 stages also increases, which in turn further increases the knowledge of parents as the children move out of the education system and start families. Conversely, if policies are adopted that delay improvements in the knowledge of children in the K-12 stage, the learning environment for their children will be more challenging than it would otherwise have been,

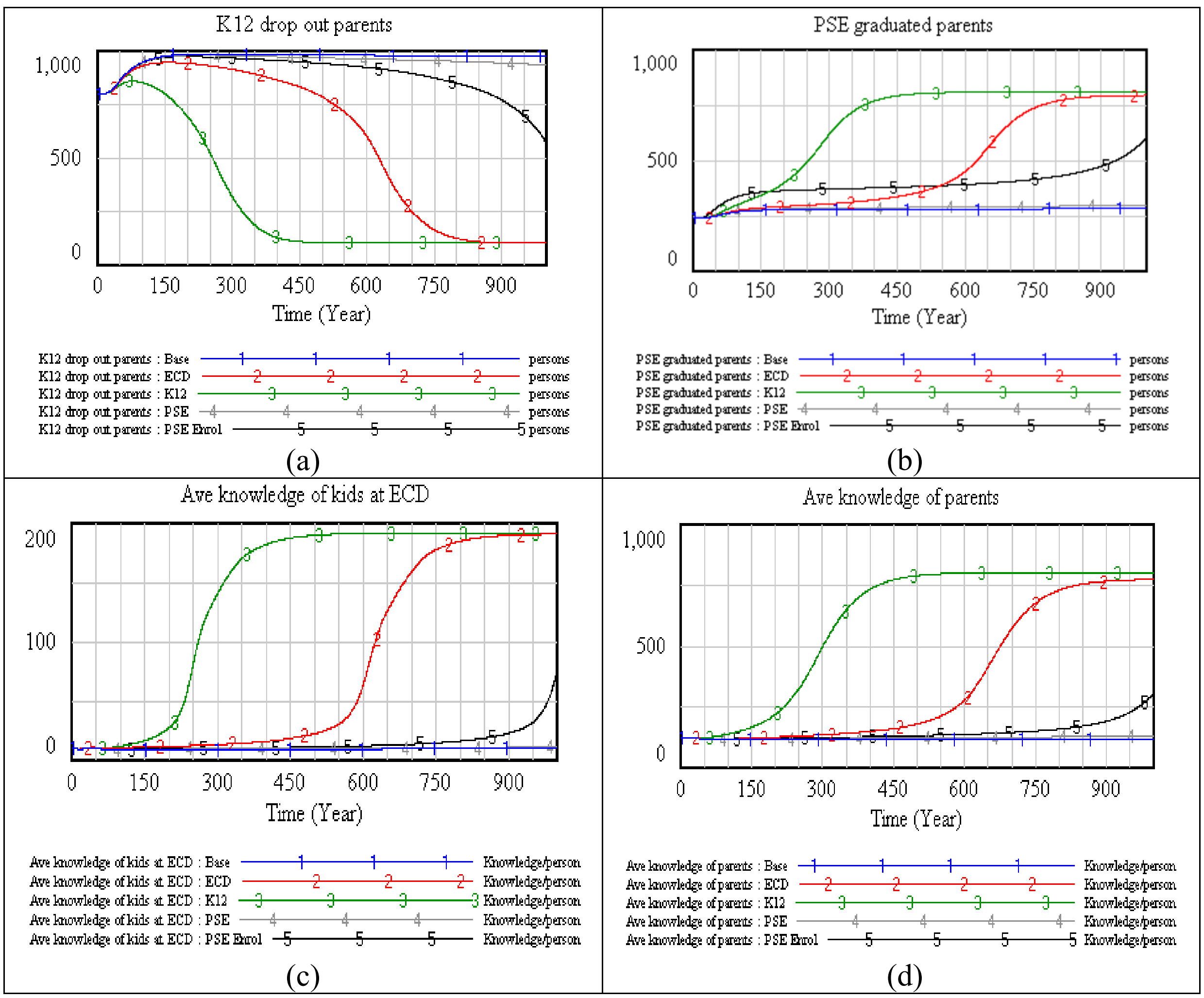

Figure 12 Simulation results of policy runs for extended period of time

Discussion

Each stage of the education system requires resources to tailor the solutions of specific problems. For example, the ECD stage needs support to run programs for mitigating problems such as poor health, and low cognitive development and motor skills of young children. The effectiveness of these ECD programs generally depends on the qualifications, experience of mentors and facilities provided at these programs. Most research overwhelmingly confirms the importance of the ECD stage, as early experience exerts a powerful influence on later well-being, builds coping abilities and competencies and helps make children physically strong and emotionally healthy. It has been argued that the ECD stage could provide strong developmental foundations in culture, education, and health, all of which influence how well children learn as they progress through later stages of the education system **(**Berman 1984, Walker 1991, Curie et al. 1995, Young 1996, and Donald 1997**)**. Armed with this knowledge how important ECD is on educational attainment, governments naturally will tend to emphasize investment in programs targeted to the ECD stage. However, the high leverage investment, that taps the power of ECD and that generates the greatest overall learning performance gain in the shortest possible time may actually lie in other stages of the education system.

The policy experiments described in this paper identify that improving learning outcomes for students in the K-12 stage would yield more benefits than policies aimed at improvement of any other stage. The improvement of K-12 learning performance increases the number of K-12 graduates and enrollment in PSE. The resulting improvement in the knowledge of parents increases their ability to provide a sustainable and effective learning environment for the kids of next generations. It is important to note that the model assumes that parents do participate in their kid's learning and that such participation is beneficial. In addition to effectiveness of the ECD programs, the environment that parents provide at home has a powerful influence on how well a child progresses at the ECD stage. The environment that parents establish usually depends on their learning from different stages including ECD, K-12 and/or PSE.

Experimentation with the model suggests that performance problems of one stage influence the magnitude of problems of other stages, and that solving problems at one stage can fix the problems of other stages. Because the education system appears to be characterized by a number of inter-connected self-reinforcing structures it is important to design policies that reflect an understanding of how the whole system behaves, rather than focusing on problems of each individual stage. In particular, policies aimed at improving overall education performance should take into account the likelihood that the most effective solutions for resolving problems in one stage of the system may be found by intervening in other stages of the system that, due to the systems structure, provide greater leverage for change.

Limitations of the model and future work

The modeling framework presented in this paper is based on many assumptions that need to be investigated in more depth using empirical evidence. For example, the shape and strength of the nonlinear relationships are based on author's intuitive or heuristic understanding about these relationships. As noted by (Lagasto et al. 1980) cause and effect relationships could be incorporated in the model to represent essential phenomena, which might otherwise be omitted due to lack of sound empirical evidence. However, any such relationships initially defined in the model should be later investigated in more depth using available empirical evidence.

In addition, extending the model by including more loops might enhance the understating about interaction between stages of the education system.

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