K-12/COLLEGIATE COLLABORATIONS IN SYSTEMS EDUCATION: THE POWER'S IN THE FEEDBACKS

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Abstract:

What traditionally passes as "collaboration" in education can more accurately be described, in systems terms, as a one-way flow of "answers." In this model, experts from the college or university bestow the "truth" upon a captive audience of k-12 educators. Each level in the educational system, however, has particular strengths and balancing shortcomings. Ignoring those complementary strengths leads to the repetitive cycles of educational fads, where innovations that match good theory with weak implementation seem to regularly alternate with wonderful pedagogy lacking fundamental content. If innovations which represent lasting improvements are to be made, then all the strengths of the various educational levels must be brought to bear in true collaboration. This requires not one-way flows of wisdom but feedback systems where the experiences of all the participants are accorded respect and the means to influence the development of the system.

Eight years of experience developing System Dynamics products and services for the k-12 educational community, and consciously seeking and responding to other educators' feedback, accords the Waters Center a powerful perspective on the essentials necessary for pursuing productive collaborations.

Much of our progress has come from consciously recognizing the developmental steps needed to move most people (students and faculty) toward an ability to creatively and productively utilize System Dynamics tools to meet their educational needs. Our early "blitz" training programs, where we expected a quick training in model building would provide teachers with the necessary tools to transform their classrooms, are illustrative of an earlier mind-set. Our experience with college and secondary students, our vicarious experiences listening to elementary, middle, and secondary colleagues, and our track-record in supporting k-12 teachers suggested otherwise. For a few who might be characterized as "educational pioneers," that training is enough; for most, it skips too many steps in the developmental process.

We now base our training efforts and classroom applications on a recognition that people most naturally and comfortably develop high level system dynamics skills through a developmental progression. This paper proposes a model for understanding how people learn and utilize systems thinking. Our classroom efforts with college and secondary students, our training outreach activities, and the supporting products we develop, are now all based on that mental model of development. Critical elements include: 1) provision of "introductory" models which address "real world" issues, are easily manipulated within limits, and incorporate visual explanation for how each system works; 2) modeling products and exercises emphasizing the

power and transferability of generic models while developing the essential mechanical skills for creating and extending models; and 3) major curricular innovation in the field of interdisciplinary education showing how insight from one discipline can effectively be used to inform another.

True, successful collaboration is a rich system of feedbacks. The theories, conjectures, and experiences of many players provide a means for designing and testing innovative approaches and for recognizing what truly is beneficial and what is not. It can be a slow and messy process, but it represents a powerful "learning curve" that will minimize the danger of System Dynamics being relegated to a status of "yesterday's fad."

Introduction:

Education is an enterprise that, while dependent on the interactions of diverse collaborators, is perceived by many of those participants as currently failing to produce desired student learning outcomes. Within this mix of collaborators, the interactions of k-12 educators and college/university faculty are particularly interesting. Any single generalization is dangerous, but some themes and variations in the system's behavior occur sufficiently often to be suggestive. Pendulum swings seem to characterize so many curricular approaches (e.g. constructivism *vs* rote memorization in math) and organizational structures (e.g. open *vs* tightly structured classrooms) that the system dynamicist has to suspect that some (many?) of the communication links necessary for maintaining effective, or at least quasi-stable, behaviors are either experiencing significant lags or are non-existent altogether.

K-12 educators are tasked with delivering products and services to their students, and college and university faculty with training and supporting the k-12 educators through initial undergraduate education, graduate training, and in-service consultation. An admittedly stereotypical relationship, although one that seems familiar to most educators with whom we work, is the k-12 educator, under pressure from some self-generated or externally-expressed concern, feeling the need to do something different, and turning to the collegiate experts for a solution. The 'crisis' is imminent; the problem is obvious; a solution is provided by the collegiate expert and implemented by the k-12 community; and some facet of the system changes. The k-

12 educators have taken action and the college experts have had their theories accepted. Yet too often the original problem recurs or the new system generates its own unanticipated and perhaps even more serious problems. Perhaps the specific problem has changed, but the underlying system is still dysfunctional and is likely to remain so until or unless the 'collaborators' are willing and able to critically challenge each other's assumptions and to honestly evaluate the results of each experiment. In short, the episodic "question asked -- answer provided" approach to collaboration needs to give way to an ongoing dialog between k-12 players and collegiate 'gurus,' as well as the various other necessary constituents in the educational system.

Such glittering, and therefore dangerous, generalities, point to issues with which we have wrestled as the Waters Center for System Dynamics has worked to develop the ways and means to assist other educators to foster more powerful uses of system dynamics in the K-12 environment. Being very conscious of our own novice status in systems dynamics when we began our outreach activities perhaps made us more willing to accept others' challenges to our "wisdom" and for us to be more willing, in turn, to challenge our collaborators' abilities to ask the best questions.

This process has spanned eight years, during which we have worked with an assortment of often gifted K-12 educators to answer the current questions as we understood them and then to critically examine the quality of the solution we provided as well as critiquing, in hindsight, whether the original questions were even the appropriate ones. It has been a fascinating journey in which we have sought to explore models for true collaboration. What we offer below, is not the definitive recipe for such K-12/collegiate collaborations, but a brief learning history and some conclusions that summarize today's state of our wisdom. Mindful of advice offered to us by Jay Forrester at early stage in our learning curve, that others will learn as much, if not more, from disclosures of missteps as from successes, we offer a candid summary of what we hope will reveal a compounding learning curve based in large measure on the power of collaborative feedbacks.

Loops in the Path; A Learning History:

Having been initially exposed to system dynamics within intense and 5 day modeling workshops, it should surprise no one that our earliest ventures in outreach to K-12 educators involved a similarly structured experience. We undertook, in 5 day "blitz training" workshops, to inculcate within our participants a working understanding of how to build models for their curricular needs.

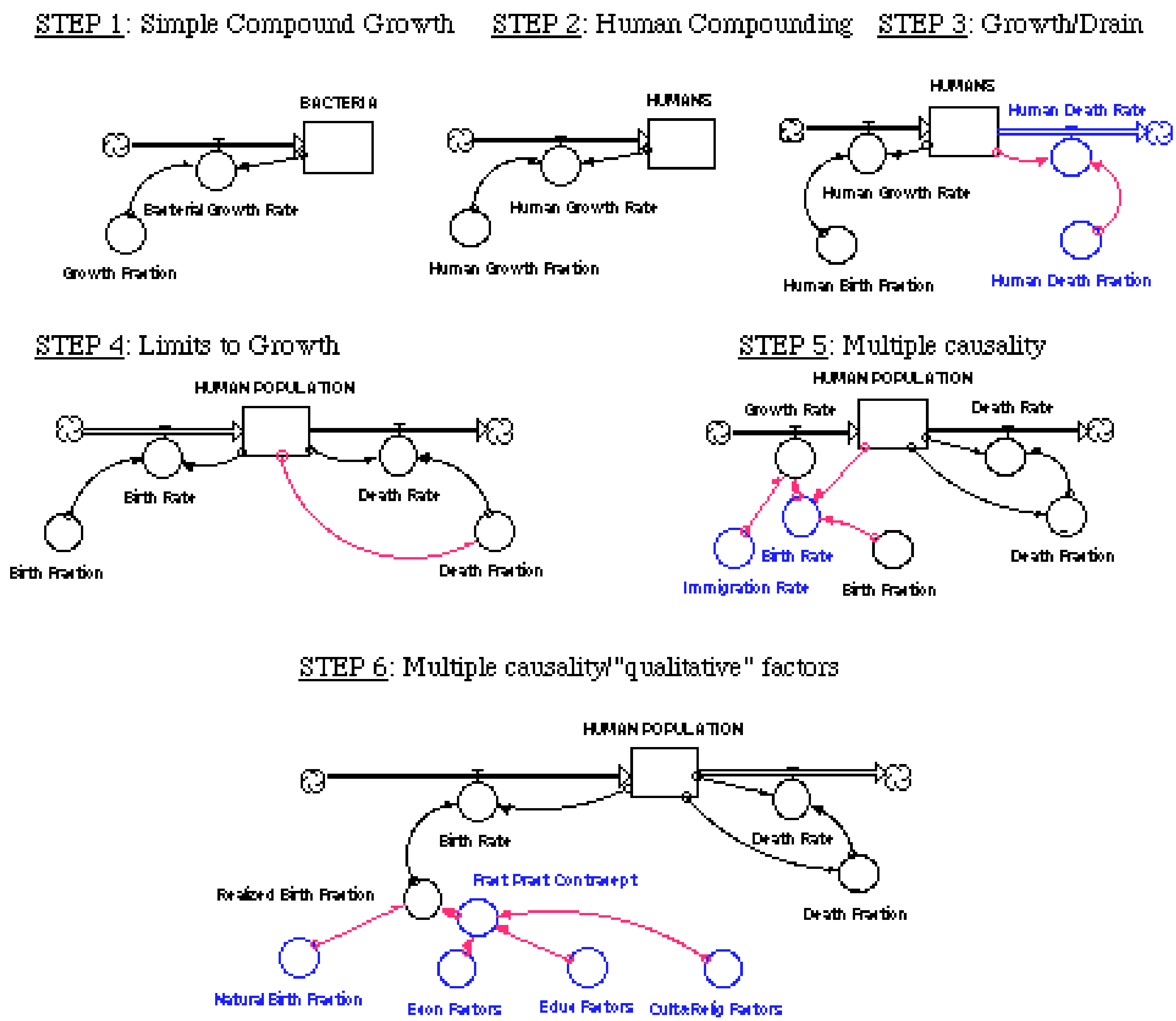
In retrospect, our own modeling skills were, at best, rudimentary. Still, in an effort to overcome the difficulties we had experienced using software manuals to develop mechanical skills, we believed we had devised an improved approach for teaching educators how to model. This approach began with a simple compounding system involving population growth, then sequentially and progressively added mechanical skills and additional modeling complexities to a basic population model that remained a central focus.

As Figure 1 indicates, our original training workshop guided participants from a simple compounding model through a series of elaborations to what we call an "interacting systems" model, in which population size or growth either affected another system and/or was affected by it. The sessions were structured so that we, using a projection screen, could first illustrate the mechanical processes, then give the participants a limited amount of time to repeat the process on their own. Four days were allotted to learning the basics and discussing the underlying systems thinking; then, on the final day, participants were released to build their own models.

In our first venture, one of the five participants was already acquainted with system dynamics, owned the software, and was anxious to strengthen his modeling skills. The others were rank novices. When the week ended, all five expressed enthusiasm for what they had learned and appreciation for our efforts. We would later find that the four novices, although departing with good intentions and a completed model, would do nothing further in terms of model building. Only the one who essentially had "gotten it" previously would continue successfully.

During the next three summers, we replicated the "blitz training" on four other occasions, engaging groups numbering between a dozen and forty participants. Modifications were incorporated into our training materials to improve the efficacy of our presentations. Responding to participant feedback, we consciously endeavored to identify parallel structures to our population model at various points in the session to illustrate the "generic" nature of the structures and behaviors being modeled. Reactions, as previously, were positive. The results, however, were invariably alike. A few each time did, in fact, "get it" and began to utilize models and modeling in their classrooms. These successful individuals were typically drawn from the ranks of math and science teachers who were already comfortable with many of the systems concepts and were reasonably facile with the math and computers. Others may have maintained an interest in the approach, and perhaps incorporated some of the systems thinking elements in their teaching, but did not actively use modeling in their classrooms. In short, as we recognize in hindsight, introducing a new way of thinking, developing the technical model-building skills, and conceiving of appropriate applications, was simply too much to accomplish in any week of

Figure 1. Sequence of Population Models Built During Original Training Workshops



effort, no matter how engaging or efficient we might be. For a few who might be characterized as "educational pioneers," and who had already been introduced to some aspect(s) of this overwhelming learning set, this training proved to be productive. For most, however, the structure was flawed.

On one level, what was clear within each session, was a discovery that educators have dramatically different learning curves. Why that should require discovery by those of us who see the same variation in our classes every day is a good question. Still, for those lacking a comfort level with computers and/or basic algebra, the experience of sitting for days and observing others progressing more easily yielded a reinforcing feedback of self-consciousness and growing doubt. Excuses and/or frustration were obvious signs of distress.

Recognizing the disparate speed at which people progressed from instruction to model building, we developed an interactive tutorial based on the sequence of population models. This tutorial would, in effect, convert our oral instructions into a series of eight lessons showing both how to build the models and then, encouraging users to build and compare their results with ours.

The reaction to this product was extremely positive. Yet, as with any system, it yielded a new discovery. While allowing people to progress at their own pace, and further offering a glossary as needed to help correct for memory lapses (a common source of distress during our training programs--"I've forgotten how to..."), our tutorial unintentionally reinforced the users' belief that proficiency in understanding system dynamics was the same as being able to replicate our increasingly complex sequence of population models. Our expectation that tutorial users could and would transfer their model-building skills effectively to other circumstances did not materialize. While in our minds human population models were merely one of an array of interesting models which could be constructed, others were not necessarily making this connection. While we had succeeded in making the process of learning the basic mechanics of model-building more accessible, it was becoming clear to us that mechanical skills alone were not enough to effect serious curricular change. At best, we observed teachers wrestling to complete a large model incorporating an abundance of detail complexity, to use as a singular or episodic exercise.

For many teachers with whom we spoke, their continued inability to develop large, functional models addressing a particular intent after a considerable investment of time and effort, led them to conclude (and rightfully so!) that the cost of investing in becoming a competent modeler exceeded the benefits. Recognizing that their mental model of cost incorporated an assumption that every model needs to be effectively built from scratch and tailored to a particular need, we realized that educators lacked a pedagogic appreciation for how some simple generic structures could effectively form the basis for a more comprehensive and, from the teachers' perspective, more efficient curricular experiment.

The decision on how to proceed from this point derived less from any systematic review of the possibilities than from the serendipitous desire of two academicians, an American historian and an oceanographer who might ordinarily communicate little if at all, to collaborate upon a topic of common interest. The result, initially taught to a collegiate audience, was entitled "Plagues and People." Based upon William McNeill's book of nearly the same name, the curricular experiment focused upon a single generic disease-transmission model as the foundation on which to play out the critical biological and historical instances in which diverse major epidemics have altered the course of human history. The basic structure used throughout the class was an infection model, modified as needed to explore, among other episodes, a smallpox epidemic in 2nd century Rome, the Black Death in Europe, and, in a final class project, development of an AIDS model focusing upon the future implications of this epidemic's spread in the United States.

This experience yielded great discoveries of our strengths in developing the power of interdisciplinary discussions based upon a generic infection model and in confirming the value of this approach in fostering college-level interdisciplinary study. We hoped that the experiment could provide a viable model allowing high school teachers, as well, to rethink the traditional discrete manner in which knowledge is presented.

While the initial response to this experiment was muted at best, the value of Plagues and People has continued to unfold over time. Among the more significant developments has been the establishment of a close working relationship between the collegiate authors of this paper and Will Costello, a physics and environmental science teacher at Champlain Valley Union (CVU) High School near Trinity College. CVU was in an innovative process of shifting from discrete courses to block schedules and team activities. After brief discussions, Will recommended we use Plagues and People as the foundation for a semester-long graduate course for interested teachers in his school to provide them with an introduction to the process of modeling while at the same time illustrating its power in supporting innovative curricula.

That experience laid the foundation for what is now an annual activity, involving not only teachers but interested high school students as well (the merger of teachers and students into system dynamics activities is the subject of a separate contributed paper by Costello et al. at this Conference). The interactions have been remarkably instructive, characterized by students' ability to master mechanical skills quickly, while teachers function as critical facilitators or "reality checkers" in drawing students' attention to the assumptions built into models and to the implications for the real world suggested by the model results. The success of this training format led us to teach "Dynamic Systems: Critical Thinking and Problem Solving" in 1997, followed most recently (1998) by a course entitled "Structures of Revolutions," which had, as its basic objective, the identification of common long-term dynamics involving relationships between population growth, wage and price dynamics, the dynamics of social movements and governmental policies, and of the gaps that develop between the current and the desired realities.

Within each of the semester-long curricular experiments, we have reserved the final month for group model-building activities. What has proven most gratifying for us is the degree to which students and teachers alike have shown courage and confidence, not to replicate our models but rather, to explore and transfer their systems thinking skills to simulate systems not covered in class. In this, as in the powerful collaborative interactions between teachers and students which don't require academics "calling the shots," we take considerable satisfaction in having progressed far beyond the original "blitz training" model.

Making Sense of the Experiences:

We began our educational outreach activities with an ambitious but seemingly reasonable desire to design and provide a training experience that would permit teachers to return to their classrooms and to utilize the power of system dynamics to transform the way their students learn. What we encountered, but did not recognize quickly, was that Education (and educators as a group) is not monolithic; there is no single all-encompassing question or need; and, as such, no one answer or service will suffice. In our experience, any program that is structured on such a linear format may experience some success (as we did with isolated individuals in our early efforts) but is likely to be quite limited in the measure of its overall success.

We now summarize our experiences through the use of a two dimensional matrix (Figure 2) that has helped us recognize the basis of both our successes and our failures. The matrix is organized to reflect variations in two dimensions of an educator's possible use of system dynamics as a tool to support learning. The horizontal axis progresses from the use of causal loop diagrams and behavior over time graphs, to the use of simple computer simulations created by others, to the manipulation and/or extension of existing models, and finally, or at least most ambitiously, to the construction of original models to meet specific needs. The vertical axis reflects the degree to which the system dynamics components are integrated into the curriculum for which the teacher is responsible. Illustrative models and other exercises can be used to introduce aspects of systems thinking or computer modeling without direct connection to any particular curriculum. Then, simple, episodic applications at the top of the axis grade into the use of related or sequential exercises which build on each other to finally the development of entire courses or units that are fundamentally based on the use of these tools.

What is much more clear to us is that valid and productive uses of system dynamics can occur anywhere in the area defined by these axes. Wise use of a single behavior over time graph in an Advanced Placement physics class or in a first grade exploration of 'friendship' can both be valuable contributions to a student's education. So can innovative development of interdisciplinary curricula or the design of systems modeling classes. Another insight that we have gained from this method of organizing our experience is to recognize that individuals tend to move through this space in a variety of only semi-predictable trajectories. Episodic uses are likely to precede curricular foundations. Successful use of the simpler tools and applications is likely to precede the effective construction of valid original models; but there is room for wide variations in patterns and rates of individual progression. Many educators will enter the space somewhere close to its upper left corner and proceed over time to the right and down. Some educators may, however, stop permanently or, perhaps, temporarily at some point in the matrix; rate of progression diagonally through the grid can similarly vary over very wide ranges. Perhaps most importantly, all of this is perfectly OK: Movement to any point in this grid can yield benefits and stoppage at any point of comfort need not be considered permanent.

NOTE: While our activity to date has been largely focused on curricular matters and the matrix here is structured on that basis, our experience with organizational issues suggest that this mental model will be equally valid and useful for these issues as well.

Using this Perspective to Revisit the Past:

The grid illuminates a fundamental flaw in our earliest efforts to train educators, first through the "blitz training," then through the self-directed Tutorial (See Figure 2). The goal of each was to develop modeling mastery without regard to curricular integration. In part, that represented a conscious and purposeful decision to avoid replicating conventional educational workshops where educators are given polished materials promising immediate "answers." Our efforts, while academically sound in some respects, were reinforcing the unintended goal of simply learning how to build ever more complex population models. For those whose curricula did not encompass population dynamics, little from our lessons was immediately transferable. For those who were successful and did, in fact, get hooked, the propensity was to use models episodically to illustrate particular points within existing curricula rather than using them as modular building blocks for developing later concepts or larger curricula.

A further weakness in that approach was in the focus on model-construction to the near exclusion of any applications to the left of that on the matrix. We do believe that the greatest value of system dynamics is realized when the individual is engaged in building original models, but other systems tools and approaches are extremely important as well. For some, these may prove sufficient: for others, they may serve as necessary intellectual stepping stones to the model-construction stage. By skipping too quickly over these earlier phases and not rewarding their appropriate use, we essentially limited the success to those who already had the mental tools and experience to make such a large leap. Our culpability, however, should be tempered with the

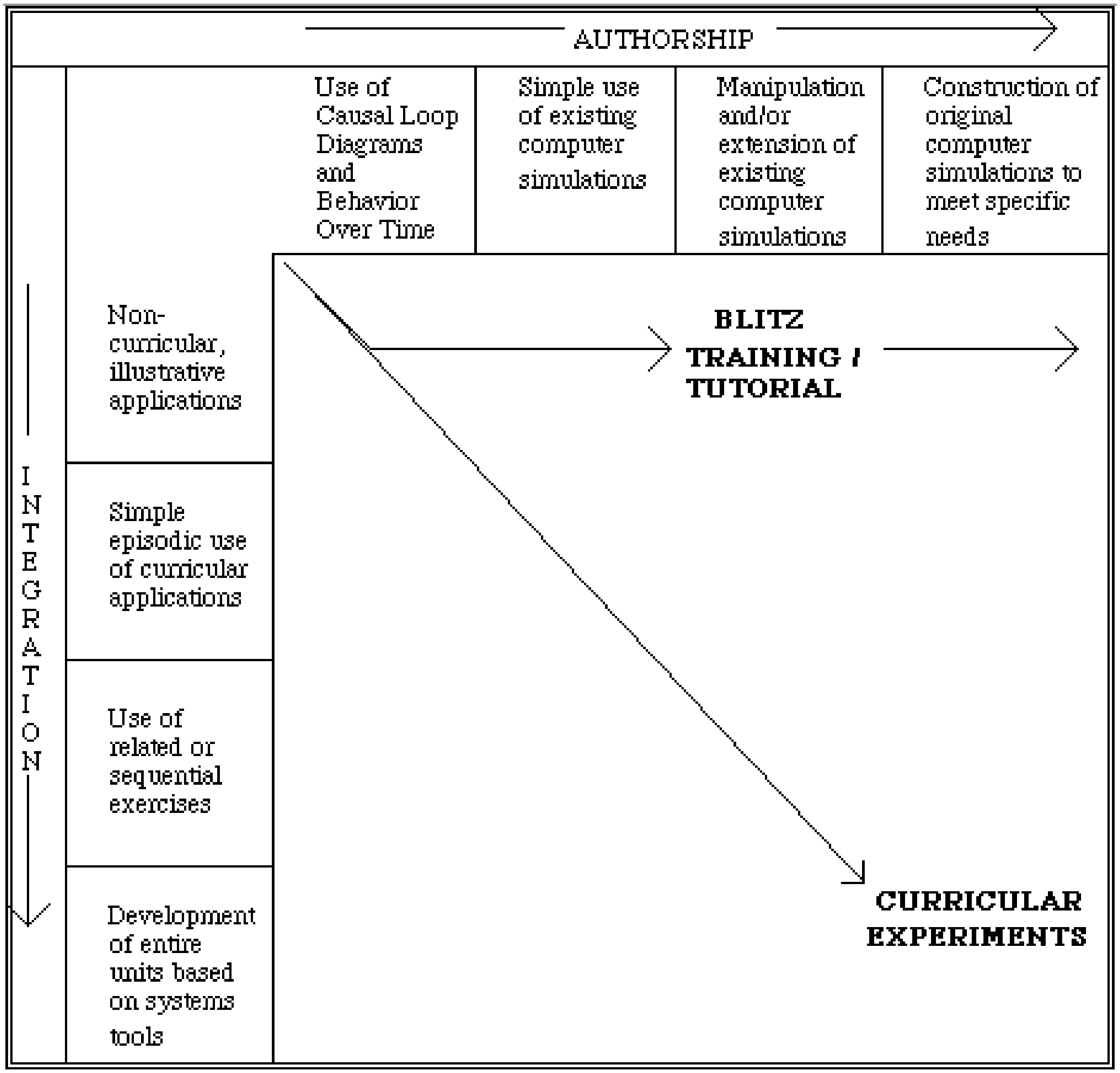


Figure 2. Matrix for Curricular Applications of System Dynamics: Initial Waters Center Programs

realization that, when we began these efforts, few "off-the-shelf" systems products were available. If models were needed in the classroom, almost certainly they needed to be built from scratch by the teacher, explaining part of our singular focus on supporting model-building skills.

The experimentation which followed, developing interdisciplinary curricula, first with "Plagues and People," then "Population Dynamics and the Human Experience" (emphasizing population growth and its relationship to food production throughout human history), and most recently by "Structures of Revolutions," constitutes a conscious effort to illustrate how a curriculum, based upon generic structures, grows to draw out increasingly better questions. Essentially, here the thrust of the effort is to move down on the matrix, at whatever horizontal position is appropriate for the class or individual in question (See Figure 2).

It is significant that "Revolutions," in its first iteration, was created and taught at Champlain Valley Union High School (rather than at the college level), and delivered to a combination of teachers and students. This collaboration has been extraordinarily gratifying for everyone involved. Essentially the mix of individuals and skills has allowed the group to move more quickly to the right on the matrix, as it was also moving down into the realm of stronger curricular integration. This mix of intellectual maturity (in general, the faculty) and modeling facility (in general, the students) has allowed more rapid diagonal progress than we have been able to realize at Trinity in our comparable experiments with students alone.

Still, it has taken three years and three of us (two collegiate academics and a high school mentor) to reach this stage in our progress in one high school that was already committed to interdisciplinary innovation. Few high schools have shown an interest in pursuing like interdisciplinary experiments; fewer still could immediately do so effectively. Thus, we realize, within the context of our grid, that this sort of curricular experimentation, while constituting an exciting and revolutionary goal for restructuring the paradigm for how learning about the "real world" can occur, similarly presumes far too much on the part of the interested, but as yet uninitiated, novice. Assertions that this audience can and should be introduced to systems through these experiments once again ignore the fact that vital steps are missing. As with the earlier rapid leap to the far end of the modeling scale, very few individuals are able to move that far in a single project. Incremental approaches, allowing individuals to move at their own rate and to pause when appropriate, will likely produce greater pay-offs, even as they require longer times and greater individual attention.

Using that Lens to Peer into the Future:

Foremost among the steps that have been missing in our previous efforts is a logical starting point which can effectively engage educators in understanding how systems thinking and system dynamics work -- through understanding and manipulating simple existing models, rather than plunging immediately into curricular design or the construction of complex models. In short, through focusing on the extreme right and lower portions of the matrix, where we found immediate gratification and to where we believe education would be well advised to move, we missed paying sufficient attention to the more logical and productive starting points for new practitioners in the upper left of the matrix. This discovery underscores yet again the richness of feedback.

In the middle of an intense five day summer workshop, specifically tailored to introduce a group of middle school math and science teachers to appropriate models and modeling opportunities, a group were chatting over lunch. One math teacher was particularly vocal about his students' ignorance surrounding basic personal finance issues. Another chimed in that the students were merely following in the footsteps of their elders. That, in turn, prompted another teacher to jump into the conversation and begin sharing his unhappiness in reviewing his most recent retirement fund statement. "If only I'd put money away earlier," he bemoaned.

That discussion quickly led to the construction of a simple model which provided a broad range of "What if" possibilities for determining how much a person would have accumulated depending on the age at which one started to save for retirement, how much one put away each year, and how much interest accrued. The simplicity of the model and the richness of its insights immediately provoked the observation that, "Everybody should know about this." Thus was born what we now call the "Demo Dozen," a collection of twelve models which allow users to assess the results of making policy decisions managing an array of "real world" systems. Included in the twelve are models involving personal finance (using a credit card, assessing the impact of long-term inflation on purchasing power, etc.) to managing ecological systems (such as a pond with lily pads or bacterial spread in a potato salad), to taking charge of major governmental initiatives (such as saving the Social Security retirement program and running the drug war).

In developing and soliciting comments on the " Demo Dozen," we have incorporated people's desire for a standardized format which accords ease of movement from one model to the next. Thus, each Demo Dozen model begins with the conceptual description of a problem which can be managed, defines leverage points which can be accessed during the simulation, and provides a "control panel" with instructions to allow the model to be run and reviewed using different strategies.

Furthermore, recognizing that a model of even a simple dynamic system can be daunting to the uninitiated, we incorporated a "debriefing" option to take people "behind the scenes" after they have explored the model. This is designed to help them better understand the feedback dynamics controlling the behavior of each system. These debriefings are purposely short, succinct, and consciously use modeling icons to capture the basic movement of "stuff" through the system and to identify the feedbacks that control that movement.

Demo Dozen has generated by far the greatest interest of any of our projects to date. Yet, in returning to the grid, it is clear that it merely scratches the surface of what can and should be produced to draw educators into developing a comfort with models which can be integrated to effect serious curricular change. For our part, the prospect of collaborating with K-12 educators to develop additional materials using the basic template of the "Demo Dozen," in order to reach specific audiences of educators and/or of students, is an exciting one. Collaborating to produce additional appropriate materials in the hands of educators should begin to introduce systems concepts into the classroom while simultaneously encouraging teachers to delve deeper into the more challenging regions of our matrix.

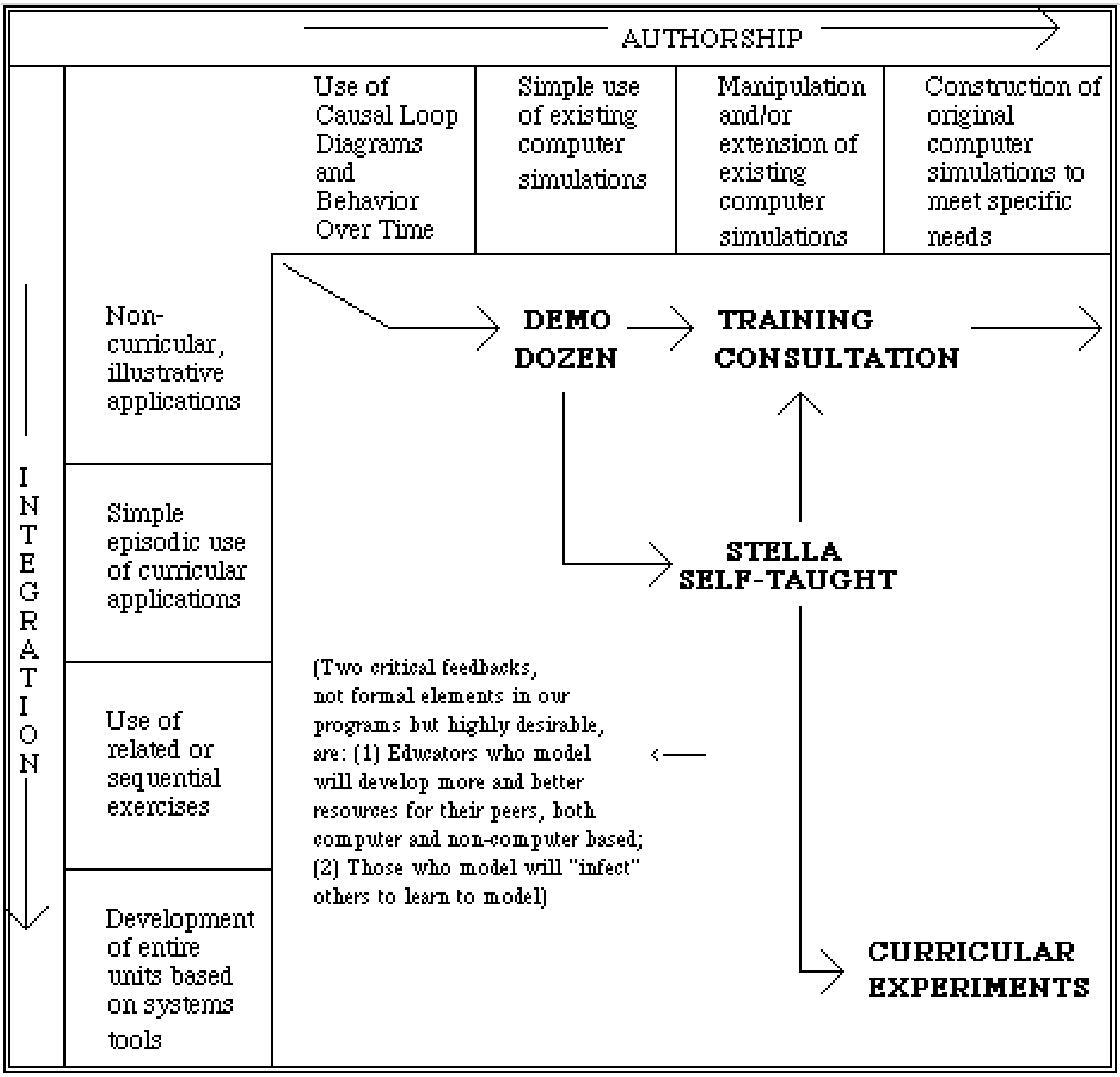


Figure 3. Matrix for Curricular Applications of System Dynamics: Current Waters Center Programs (**in bold**)

Still, for those appropriate materials to be generated and disseminated, it is critical that some contingent of educators aspire to become modeler-builders. For that reason, we continue to modify our training materials to improve teachers' willingness and ability to persist in what must be a serious investment of time and energy. Recognizing that the earliest part of the learning curve is the most difficult, we have endeavored to provide large numbers of specific, but parallel, examples to illustrate the transferable potential while learning about systems. Thus, starting with linear systems, users build and assess dynamics associated with traffic jams, with drinking and its impact on blood-alcohol, and with personal finance issues. As users gain confidence in their skills and understanding of the power of generic transferability, they progress into the realm of more complex, non-linear systems. Thus, we show how to adapt a simple infection model into a model capable of analyzing market penetration and into another for understanding the dynamics of social and political behaviors.

This new "STELLA SELF-TAUGHT," a collection of 16 lessons currently in development, is being structured to guide the novice interested in modeling through an exciting range of models supporting, not just technical mastery and an understanding of systems thinking and generic structure transferability, but more critically, construction of new and better materials for classroom application. This accords additional opportunities for educational collaboration within schools, where, we have found, the model builder is rarely one and the same with the "idea" person, who, in turn, is separate from the reality checker.

Conclusions:

We now base our training efforts and classroom applications on a recognition that people most naturally and comfortably develop high level system dynamics skills through a developmental progression. This paper proposes a model for understanding how people learn and utilize these skills and tools. All of our classroom efforts with college and secondary students, our educational outreach activities, and supporting products are now based on that mental model of development and serve to move participants progressively down and right on the matrix. Critical elements include: 1) provision of "introductory" models which address "real world" issues, are easily manipulated within defined limits, and incorporate visual explanation for how each system works; 2) modeling products and exercises emphasizing the power and transferability of simple generic models while developing the essential mechanical skills for creating and extending models; and 3) major curricular innovation in the field of interdisciplinary education demonstrating how insight from one discipline can effectively be used to inform another.

We are far from having exhausted the possibilities. The current version of our grid (see Figure 3) suggests how and what feedbacks might be developed to facilitate appropriate growth and to define future collaborative activities. Within the grid, we believe there is abundant room for us and others to continue to experiment with new methods for involving educators in ever broadening discussions to use system dynamics in promoting positive change and inspiring better student achievement. The challenge, in all cases, is not to rush the process nor to defer to academics to construct some definitive collection of curricular materials which can easily but thoughtlessly used by everyone. To do so, we maintain, would return us to a linear dynamic (collegiate answers to K-12 questions) in which, when the system dynamics "gurus" inevitably fail to provide all the answers, systems will be discarded in favor of a new fad.

In sum, system dynamics must not allow itself to be caught up in the crisis orientation which traditionally spearheads the call for change. If we are to contribute to legitimate educational change through the use of systems thinking and dynamic modeling, we must do so with the appropriate humility, patience, and with a recognition that, if we are to effect a revolution in the way in which education and knowledge is structured, it is more likely to succeed as a long-term evolutionary process. This will involve thoughtful, open, and honest collaboration between academics and K-12 educators. At this relatively early stage in our collective learning curve, neither academics nor K-12 educators should imagine themselves in possession of all the answers nor even of all the questions. For the better questions to evolve and the dynamic answers then to follow, we must continue to listen and adjust rather than simply to be satisfied with our current activities.