Introduction:

In 1988, Massachusetts Institute of Technology (MIT) Professor Emeritus, Gordon Brown, found his way into the classroom of one middle school science teacher in Tucson, Arizona US and shared system dynamics modeling software with him. The teacher saw potential applications for embedding dynamic models into the learning process as a way to enhance and deepen student understanding of science content. He began creating instructional materials that allowed students to learn curriculum from a problem-based, learner-centered approach. For example, as part of an ecological study, students explored interdependent, dynamic relationships while making decisions about where to locate various amenities in a new national park. Students had to consider the impacts their decisions would have on the system as a whole, while operating within a limited financial budget. Young people often don't forget these experiences, since they exemplified meaningful work, and they carry the essence of that learning with them into their adult lives[1].

Over time, Professor Brown and that one middle school teacher directly and indirectly impacted use of systems thinking and dynamic modeling beyond this one classroom - to other teachers in the same school, to other schools in the same district, to other districts in the same city, and to other schools across the nation and in other nations. The increasing trend of use could, of course, not have occurred without a network of educators who saw the benefits for their students and who worked and continue to work on developing capacity to apply systems thinking and dynamic modeling within classroom instruction and organizational learning. Perhaps some important questions to consider are "How and why has it spread thus far?" and "What keeps it from spreading more quickly?" One partial answer begins with yet another question: "After twenty years, what evidence exists that using systems thinking/dynamic modeling[2] (ST/DM) methodologies has a positive, desirable effect on student learning?"

Four areas of evidence are available, each in different quantities and with different measurement criteria. The largest body of evidence is found within the anecdotes of teachers who describe thinking and learning results for their students. Although smaller in quantity, action research (a methodology used to investigate a particular question about learning) and student survey results allow for observation of some general trends relating to student learning/thinking[3]. Finally, empirical research studies are less prevalent, but have occurred within K-12 classrooms.

[1] A longitudinal video study, …that School in Tucson, shows adults reflecting on their learning experiences in middle school. Available from the Creative Learning Exchange at www.clexchange.org/thatschoolintucson

[2] The term dynamic modeling is used in this context to include computer modeling using system dynamics software, such as STELLA or Vensim, as well as other types of models, such as dynamic physical or kinesthetic modeling/simulation.

[3] The stories and research are a result of contributions from many individuals over time. Many thanks to Tracy Benson, Barbara Casanova, Caryl Crowell, Frank Draper, Sheri Marlin, Dave Mason, James Ranney, Joan Scurran, Shea Van Rhoads, and Heng Wenyu whose specific experiences are shared here.

Anecdotal Evidence:

Although some may not give much merit to anecdotal reports, for teachers in the classroom, often the strongest evidence is what they see unfold over time within their own students. Teachers can see how the use of one methodology versus another produces differing effects on their students' abilities to think and learn about systems being studied. Over the course of an individual day, a unit of study, and a school year, teachers assess student progress toward identified learning goals and modify instruction based on that progress.

Whether the system being studied is characters within a novel, mathematical equations, ecological systems, or the dynamics of music, teachers can see how the use of visual tools can increase student understanding, and they can describe these effects on understanding with clear experiential evidence[4]. A primary teacher (of students ages 5-8) used a simple representation of the number of visitors at the zoo, based on the rates of individuals entering and leaving the zoo. The experience helped her kindergarten students build the foundation for addition and subtraction as well as understand the systems concept of an accumulation that changes over time.

An intermediate teacher (of students ages 8-11) described that being able to represent and discuss change over time when exploring a literary novel helped her students see the whole, rather than just the events of a particular chapter. A middle school science teacher (of students ages 11-14) saw how after kinesthetically experiencing a system and running a computer simulation, students could use an operational understanding of how infections can spread to talk about the trends produced in terms of economic, political and cultural implications. A high school social studies teacher (of students ages 14-18) described how systems

thinking strategies he employs within his classroom allowed students to take a look at the bigger picture and realize that there is not necessarily one reason that a problem exists in a particular system.

In addition, teachers have described how students often find ways to connect the learning in the classroom to real-life situations. Primary students saw connections to dynamics on the playground and decided to use systems tools to help them understand what was affecting student and adult satisfaction over time. A middle school student, who had used the escalation archetype to explore patterns during the Cold War, recognized that a similar dynamic was occurring between one of his teachers and himself. The tool became a way to talk about the situation in a non-defensive way and find leverage for improvement. A high school student used his understanding of system dynamics models to study a current local issue, an invasive species in the US Pacific Northwest, and then presented his learning at the International System Dynamics Conference.

These stories represent just a few of the "Aha" moments for teachers and students. Over the last 20 years, a multitude of stories have inspired many to see how the visual nature of systems strategies can help scaffold learning for students and help them organize and better communicate their thinking.[5]

[4] Also see the work of Robert Marzano et al, who through a meta-analysis of studies relating to instructional strategies, found that the use of non-linguistic representations was a key strategy for increasing student achievement.

[5] Video Segments of teachers and students describing the rationale for using systems thinking strategies can be viewed at:
http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=hydrologyprojectsml&auto=true
http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=systemsthinking09&auto=true
http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=SystemsThinking.flv&auto=true
http://www.watersfoundation.org/webed/mod1/mod1-5-1.html

Action Research:

Many of the same teachers who had stories to share wanted to go further in their exploration of how ST/DM affected their students' learning. They and others took on the challenge of completing one or more action research projects. Classroom teachers first determined and refined an action research question that related to how ST/DM strategies would affect students reaching curricular goals. The question provided a focus for the teachers as they described the desired student learning, the assessment plan to determine whether or not students achieved that learning, and the instructional use of systems strategies. Teachers then collected and analyzed data on student performance levels before and after the use of particular systems strategies as part of instruction. Through this analysis, they could go back to the original question and draw some conclusions, based on noted patterns. Some teachers participated in the action research process in subsequent years to further refine their methodologies and add to the body of results.

Based on a meta-analysis of all action research projects, a few of the initial trends[6] noted were

- Students use systems thinking tools to clarify and visually represent their understanding of complex systems. This visual approach allows the students and others to interact with and explore thoughts, perceptions, and mental models with precision and clarity.
- Systems thinking tools help students make connections between curricular areas and relevant life experiences.
- Students of all ages learn and independently use systems thinking problem-solving strategies.
- When using systems thinking concepts and tools, many students show increased motivation, engagement, and self-esteem.
- Systems thinking concepts and tools help students develop as readers and writers.

For example, the use of ST/DM within the context of reading and writing fostered students' abilities to deepen understanding of a literary piece. Students used ST/DM strategies to help them retell and summarize a piece of writing. They analyzed character, plot, setting and theme along with the relationships among these literary components, and they identified points of view such as the authors' and characters' mental models.

This marriage of systems strategies with specific educational standards is one important aspect of an action research project conducted within the classroom. Because the specific skills are directly connected to educational standards of learning that are set and tested at state and federal levels, one question is simply, is the use of ST/DM as an instructional strategy an effective way to learn class material? If the answer to this question is "Yes," as the trends thus far suggest, then that alone is a compelling rationale for use. To take it a step further, another question to explore is, "Do students learn more using ST/DM strategies than they would have otherwise?" One way to consider this question initially is to engage students in reflecting upon their own learning.

[6] Additional information about the general trends and initial conclusions are available in the research section of the Systems Thinking in Schools, Waters Foundation website: www.watersfoundation.org

Student Surveys:

Over the course of their 13 years in school, high school students have experienced hundreds, perhaps thousands, of different

instructional methodologies. In some ways, we might look to them as experts in the field of learning, since different methods have either helped or not helped them as individuals learn the expected outcomes.

Each year over the course of an eight-year period from 1998-2005, graduating seniors at one high school (HS) were asked to self-assess the impact of using ST/DM tools on learning subject-area content. In addition, data was collected from middle school (MS) students from 2003-05. Students were asked to identify the tools they had used at some point during their school experience from Kindergarten through 12th grade. They also identified contexts in which they recalled using the tools, including specific computer simulations. Data for the last three years for both groups are included in the table below, when these three questions were asked each year.

Survey Question	Average 'Yes'
Was using systems concepts/tools an effective way to learn class material?	MS 64% HS 80%
Do you think you learned **more** by using these systems concepts/tools/ simulations than you would have otherwise?	MS 56% HS 59%
Have you used or could you imagine using systems concepts/tools at times when not required, either in schoolwork or in social situations with friends/family?	MS 22% HS 31%

Keeping in mind that students have very different learning modalities, to say that any one instructional strategy is effective for 80% of high school seniors, creates a strong rationale for using that methodology as one way to reach a large percentage of students. Perceptual data, although not always aligned with factual data, can have a powerful impact on action. Although implied in the questions, students who see a strategy as effective will be more apt to be engaged in the learning process while using that strategy.

To further reinforce this premise, a recent high school graduate from Nanjing, China who presented his work at the 2009 International System Dynamics Conference[7] gave some advice to a group of attending K-12 teachers and system dynamicists. His challenge to them was to use systems thinking to engage students, to actively interest them in being involved in their own learning. For him, because his teachers integrated ST/DM through engaging interdisciplinary projects, he became excited about his own learning, and he had the tools needed to explore, process, and connect the subject-area learning to something meaningful. Listening to student perspectives such as these add yet another facet to determining overall effectiveness.

[7] See the System Dynamics Society's website for additional information about the conference.

Empirical Study:

Empirical studies within the K-12 environment have been limited, although a number of studies have been completed at the undergraduate and graduate level[8]. One recent study, *Assessing the effectiveness of systems-oriented instruction for preparing students to understand complexity*, by Richard Plate has been completed within schools supported through the Systems Thinking in Schools, Waters Foundation Project. Plate designed his research to include two studies – one with middle school students and one with undergraduate students. Each study included a group that utilized ST tools (the systems group) along with a group that did not use these methods (the control group). The behavior of the groups was compared to one another as well as to a group of perceived experts within the system dynamics field.

The systems groups were able to develop causal maps that were, "on average, more similar to expert maps than were their respective control groups." (Plate, 2006) Using a scoring rubric, Plate compared the maps based on a number of criteria including identification of key variables and the representation of feedback loops. The systems groups scored more similarly to the expert groups than did the respective control groups in both studies. Plate concluded that, "Systems groups displayed a greater understanding of the situation described in the article than the control groups. While the differences observed are not definitive enough to make strong claims about systems-oriented instruction based only on these studies, they are strong enough to warrant further studies assessing systems-oriented instruction's worth as a pedagogical tool" (Plate, 2006).

As Plate suggests, additional research within K-12 is needed to come to more firm conclusions about the effects of instruction that incorporates systems strategies.

[8] System dynamics related research is available from many online sources, two of which are the Creative Learning Exchange at

http://www.clexchange.org/search/cle_docsearch.asp?category=Research and the System Dynamics Society at http://www.systemdynamics.org/society_activities.htm.

Moving Forward:

The evidence that does exist relating to K-12 use of ST/DM methodologies is not currently available in one easily accessible, central location. One challenge then becomes adding to this body of evidence while making it accessible and transparent to those seeking it. Best teaching practice is rooted in data, whether that data is collected by teachers in a classroom or by researchers in a controlled setting. Having that data accessible potentially removes one barrier to more widespread use of systems thinking and dynamic modeling.

A challenge for future researchers within the K-12 environment is to consider the scope of what to measure along with the potential audience for the resulting conclusions. Do we want to know how ST/DM affects student learning of educational standards? Do we want to measure understanding of system dynamics concepts, such as accumulations and feedback? Do we want to measure lifetime benefits? During a K-12 educational roundtable at the 2009 International System Dynamics Conference, an interesting mental model surfaced as part of the conversation. The group was discussing the importance of research to validate the effectiveness of ST/DM. One participant contributed that no other field must prove through research that educating students, say in math or science, makes the world a better place. Considering this interesting insight could provide direction for future studies, helping us determine and clarify key research areas that will best communicate the effects over time on student learning and life experience as well as help educators refine educational pedagogy to better meet the needs of students.

The focus of the Systems Thinking in Schools project continues to be building the capacity of educators to deliver academic and lifetime benefits to students through systems thinking and dynamic modeling concepts, habits and tools. Participating educators have worked over time to determine, through anecdotal evidence, action research, surveys, and empirical study, to what degree we've succeeded in achieving that desired mission. Yet, we are still at the initial stages of creating the desired large body of evidence. Twenty years may seem like a long time, yet when compared to development time for other innovations, implementation of systems thinking and dynamic modeling within K-12 education has come a long way within a short period of time in determining what's logistically possible with students as young as 4-years old. So what comes next? For us, it's simply getting back to doing what works with students in classrooms, and when feasible, enhancing the body of evidence for the purpose of sharing that work beyond our own doorways.

References

1. Forrester JW. 1992. System Dynamics and Learner-Centered Learning in Kindergarten through 12th Grade Education. http://sysdyn.clexchange.org/sdep/Roadmaps/RM1/D-4337.pdf. Creative Learning Exchange: Cambridge, MA. May 2006.
2. Creative Learning Exchange. www.clexchange.org.
3. Marzano, Robert J., Pickering, Debra J., Pollack, Jane E. 2001. Classroom Instruction That Works. ASCD.
4. Plate Richard. 1996. Assessing the effectiveness of systems-oriented instruction for preparing students to understand complexity. http://www.watersfoundation.org/index.cfm?fuseaction=content.display&id=264. August 2009.
5. STIS WebEd - Video Segments. Waters Foundation. 2008. Retrieved from http://www.watersfoundation.org/webed/mod1/mod1-5-1.html August 15, 2009
6. That School in Tucson. 2008. DVD. Creative Learning Exchange. www.clexchange.org/thatschoolintucson
7. Video Segments, Systems Thinking. Catalina Foothills School District. 2009. Retrieved from http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=hydrologyprojectsml&auto=true>http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=systemsthinking09&auto=true http://www.cfsd16.org/public/_century/centSkillVideos.aspx?vid=SystemsThinking.flv&auto=true August 15, 2009
8. Waters Foundation Action Research. Waters Foundation. Retrieved from http://www.watersfoundation.org/index.cfm?fuseaction=content.display&id=263 August 15, 2009
9. Waters Foundation. 2009. www.watersfoundation.org.

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Anne LaVigne is a coordinator of the Waters Foundation, Systems Thinking in Schools project. She has worked for the last 14 years to build capacity of educators to use systems thinking and dynamic modeling strategies within instructional and organizational settings. She facilitates professional learning experiences and designs instructional resources and online learning environments that integrate a variety of modalities including visual, auditory, and kinesthetic to meet the individual needs of learners.

With the support of the Waters Foundation, a private, charitable foundation founded in 1957 by Jim and Faith Waters, the work of the Systems Thinking in Schools Project continues through a network of educators who develop the capacity of K-12 educators to apply systems thinking and dynamic modeling within classroom instruction and organizational learning. To learn more about the work of the project and available online resources, visit the project's website. All resources on the website are freely available for non-profit, educational use.
