SRMN
STEM Research and Modeling Network

Proceedings from the Inaugural Meeting of the STEM Research and Modeling Network (SRMN)

November 13 - 14, 2008
Ewing Marion Kauffman Foundation
Kansas City, Missouri

About BHEF

BHEF is an organization of Fortune 500 CEOs, prominent college and university presidents, and foundation leaders working to advance innovative solutions to the nation's education challenges in order to enhance U.S. competitiveness. BHEF brings together an extraordinary coalition of corporate, academic, and foundation members to influence public policy and inspire other corporate, academic, and foundation leaders to act. Online at www.bhef.com.

About the SRMN

The STEM Research and Modeling Network (SRMN) was founded in 2008 through an innovative partnership between the Business-Higher Education Forum (BHEF), Raytheon, and The Ohio State University (OSU). As an open, networked community, the SRMN is committed to bringing together researchers, modelers, educators, and funders to help address our nation's most persistent education challenges.

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This publication is available at www.STEMnetwork.org.

Foreword

The Business-Higher Education Forum (BHEF) is pleased to present these proceedings from the inaugural meeting of the STEM Research and Modeling Network (SRMN), held in November 2008 with the generous support of the Ewing Marion Kauffman Foundation at their facility in Kansas City, Missouri. The meeting represented a significant milestone for the SRMN, and these proceedings reflect the perspectives and direction that the participants provided.

At the Kauffman meeting, founding SRMN partners—BHEF, The Ohio State University and the Raytheon Company—convened a diverse group of nearly 40 experts in STEM education, research, and policy, as well as system dynamics modeling and open source development. The shared motivation of these forward-thinking experts to improve STEM education provided the impetus for the meeting.

The meeting introduced participants to a new tool to assist in improving STEM education—a system dynamics model of STEM education in the United States. Developed by the Raytheon Company, this national-level model tracks the flow of students through the K-12 education system, into STEM majors, and into STEM industry or teaching. The initial version of the model sorts students into STEM-interested and STEM-uninterested, with mathematics proficiency serving as a proxy for STEM interest.

As the proceedings show, the participants drew on their diverse perspectives and expertise to critique the research and assumptions that underpin the model and suggest ways to enhance the model. In addition, those in attendance launched a collaborative network—the SRMN—that is committed to conducting and collecting research as well as using tools like the Raytheon model to strengthen STEM education for all students and increase the number of STEM graduates in the United States.

Much progress has been made since the Kauffman meeting, including a second SRMN meeting in Miami, Florida, in February 2009. Motivated by participants' input, BHEF and partners The Ohio State University and Raytheon have collaborated to undertake key revisions to the initial version of the model. Members of BHEF and the SRMN, including ACT, have contributed to these efforts by providing data and expertise. As a result of these efforts, the following changes will be evident in the next version of the model:

- The model will include separate flows for combinations of high- and low-STEM interest and high- and low-mathematics proficiency, for each gender.
- The underlying census data will be updated.
- The research base will be updated and expanded.

The new version of the STEM education system dynamics model will provide a more robust platform for a release into open source in the spring of 2009. The open-source release will mark another important point in the model's development, and the following proceedings document the initial steps to build a useful tool for policymakers and other users as they develop a STEM research agenda and work to improve STEM education in the United States.

Introduction

Concern that the U.S. education system is failing to keep pace in the global talent race has resulted in a spate of actions aimed at improving science, technology, engineering, and mathematics (STEM) education in this country—disciplines responsible, in part, for cultivating and supplying our nation's system of innovation with top talent that can keep the U.S. and its economy competitive. Major corporations and private foundations are investing significant resources to address this challenge, and state and federal government agencies are striving to strengthen STEM education in K-20 systems.

In 2005, the Business-Higher Education Forum (BHEF)—an organization of Fortune 500 CEOs, prominent college and university presidents, and foundation leaders—launched a STEM initiative. Led by co-chairs Warren Baker, president of the California Polytechnic State University, San Luis Obispo and William Swanson, chairman and CEO of Raytheon Company, BHEF's STEM initiative seeks to double the number of STEM college graduates by 2015 by strengthening the math and science teaching workforce and pursuing other promising strategies to create pathways that lead to STEM careers.

Motivated by this challenge, Raytheon dedicated a team of systems engineers to develop a creative approach to helping stakeholders understand the complex array of factors involved in doubling the numbers of STEM graduates. The result was a systems dynamics model of the K-16 education and STEM workforce systems. This new tool can help researchers, policymakers, and funders explore via simulation the effects of different policy and programmatic interventions on the number of STEM graduates. With the model came the vision of creating an open-innovation community. This community would work collectively to continually refine the model and tackle key research questions underpinning the broader challenge of improving STEM education outcomes.

BHEF and its STEM modeling partners, Raytheon and The Ohio State University, convened a group of 40 researchers, policymakers, educators, and funders in November, 2008. Generously hosted by the Ewing Marion Kauffman Foundation in Kansas City, Missouri, and with additional support from the Bill & Melinda Gates Foundation, this meeting served as the official first convening of the STEM Research and Modeling Network (SRMN).

The goals of the November meeting were to

- analyze the potential value of using predictive modeling in education;
- explore the model developed by Raytheon and discuss potential improvements to and applications of the model;
- discuss the STEM Research and Modeling Network and its activities;
- identify opportunities for ongoing SRMN participation.

The clear consensus among participants was that Raytheon had developed a robust prototype model with valuable potential for improving our understanding of STEM education. Participants also expressed a strong interest in refining the model to make it available as an open-source tool and in forming an open-innovation community to further refine the model and explore its utility in education policy and research. Raytheon committed to implementing some of these refinements before releasing the next version of the model in 2009. These proceedings summarize the November 2008 meeting and identify the next steps for the SRMN. To keep apprised of current SRMN activities, visit www.STEMnetwork.org.

Predictive Modeling: A Valuable Tool for Education Policy

Engineers from Raytheon introduced SRMN meeting participants to predictive modeling as a valuable tool for studying a system when one cannot actually experiment on the system. Used in other fields, predictive modeling has long been helpful in studying complex systems such as project management workflows and supply chains. Although systems models have rarely been used in education, they have the potential to

- offer an organized and comprehensive approach to understanding the complex, multi-level nature of the U.S. education system;
- simulate the impact of policy and programmatic interventions over time;
- demonstrate the effects of changing various factors or variables within the education system;
- provide a common platform for analysis, research, and dialogue among the often disconnected education stakeholders of policymakers, practitioners, funders, and researchers;
- inform the development of a more coherent education research agenda.

Using System Dynamics to Explore STEM Education

System dynamics modeling is based on a high-level view of a system—referred to as a dynamic hypothesis—that is used to develop a conceptual understanding of the system. Each dynamic hypothesis includes causal feedback loops that connect different parts of the system; these feedback loops drive the overall behavior of the system.

Raytheon's model is a stock and flow model. In system dynamics modeling, a stock represents "things" that accumulate—numbers of students, for example. Flows (either into or out of the system) change the stock over time. As an example, high-school graduation rates (flow) change the number of students in the K-12 system (stock).

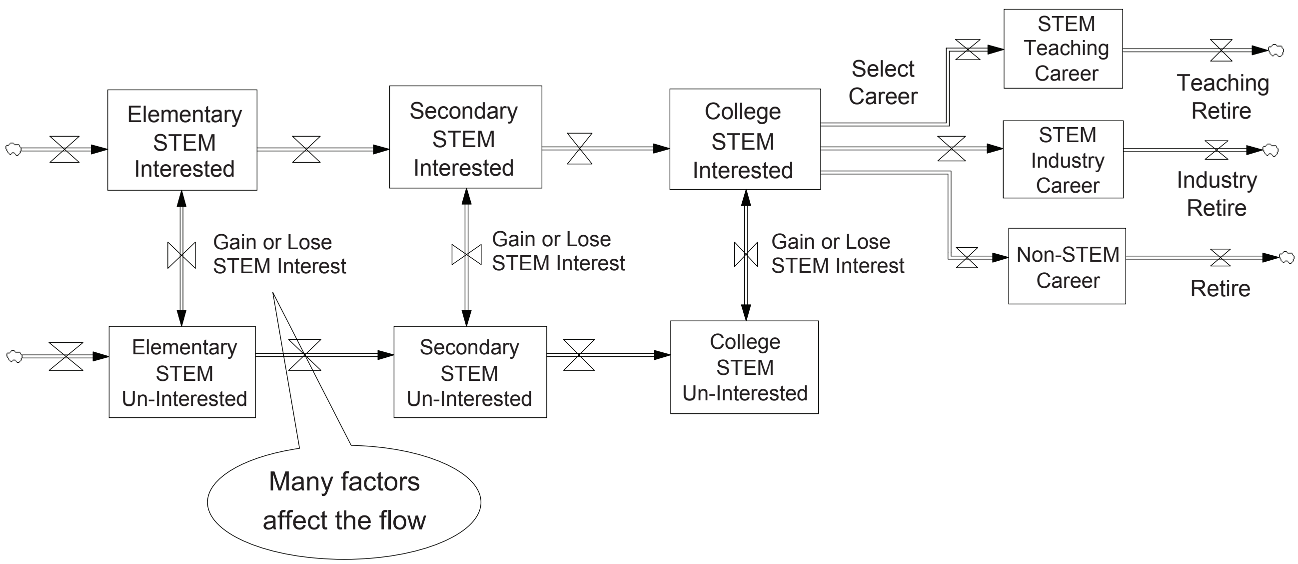
In this model, the stock is the overall number of students[1] who progress through the grades. The flow represents a change between STEM-interested and STEM-uninterested (Figure 1). It is important to note that standardized test scores in mathematics serve as a proxy for student interest in STEM in this initial version of the model. Thus, at the K-12 level, "STEM-interested" refers to students who have scored proficient or above on the National Assessment of Educational Progress (NAEP) mathematics test.

"Systems models have the potential to offer an organized and comprehensive approach to understanding the U.S. education system."

Students' progression through the education system and into the workforce is depicted in Figure 1. On the far left side of Figure 1, students are born and enter the education system. They progress from grade to grade, graduate from high school, attend college, get a job, gain experience, and eventually retire (as shown on the far right side of Figure 1).

1 The stock of students was determined using data from the U.S. Census and Bureau of Labor Statistics.

Figure 1: Simplified Representation of the Student Flow Model



In the model, the flow through the education system is divided into three segments—one each at the elementary, secondary, and postsecondary levels.[2] Each of these segments is divided into two flow paths: students who are interested in STEM and those who are not. The top flow paths in Figure 1 represent STEM-interested students and the bottom flow paths include students who are not interested in STEM.[3] STEM-interested students who graduate from high school and pursue a STEM major or an education major related to STEM in college flow into the postsecondary portion of the model, where the paths represent students who become teachers or go into STEM industry. The cohort of students who do not pursue a STEM major in college, or an education major related to STEM, is not included in the model after the high school graduation point. Thus, the postsecondary portion of the model includes only those students who enter college as STEM-interested.

Dynamic Hypotheses of the STEM Model

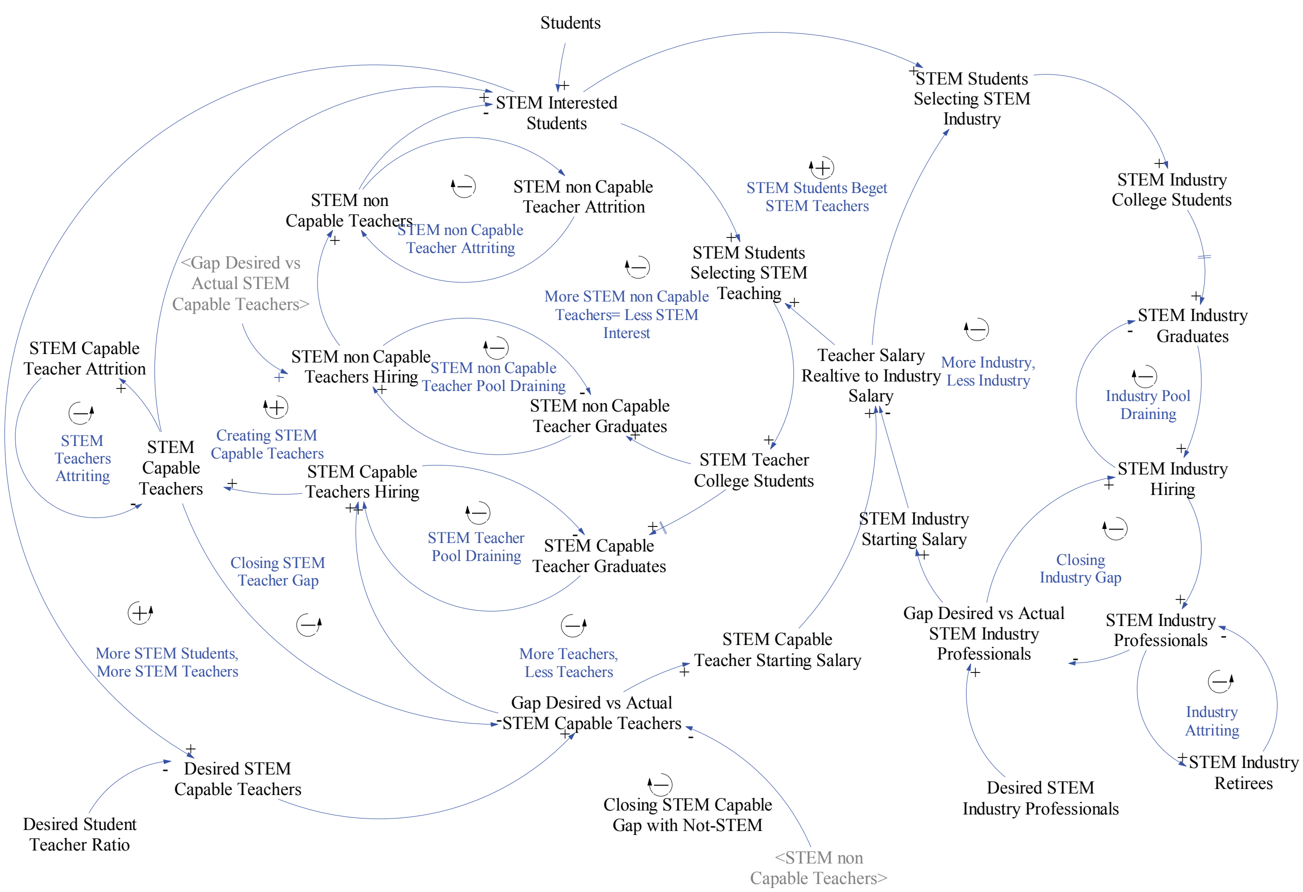
Raytheon's model includes 14 validated dynamic hypotheses and 227 independent variables for influencing the number of students who are capable and interested in pursuing careers in STEM disciplines. Model developers used published research on teacher quality and on STEM persistence in college to develop and test these dynamic hypotheses, identify the variables that influence STEM persistence, and determine the relationships between those variables. This research is at the core of the model because it forms the basis for the mathematical formulae that underpin the model and for the coefficients that determine the strength of various influences on STEM interest (defined at the K-12 level as proficiency on standardized mathematics tests).

2 The model is broken into the following grade-level bands: K-4; 5-6; 7-8; and 9, 10, 11, and 12.
3 Students younger than grade 4 are not characterized in the model because there are no quantitative, national data on mathematics proficiency—the proxy for STEM-interest—before grade 4.

At the K-12 level, several of the dynamic hypotheses focus on the influence of teachers on students' STEM proficiency and on mechanisms for increasing the number of STEM-capable teachers. In the postsecondary portion of the model, the dynamic hypotheses focus on supports—social networks and mentoring or bridge programs—that influence student persistence in STEM.

A sample dynamic hypothesis is depicted in Figure 2. Arrows show the causal relationship between the variables and indicate the flow of change. A positive (+) sign on the arrow indicates positive flow, i.e. when the value of the input variable increases, the output variable also increases. A negative (-) sign on the arrow indicates negative (or opposite) flow, i.e. when the value of the input variable increases, the output variable decreases. Positive feedback loops create the significant changes that are required to increase the number of STEM graduates.

Figure 2: Dynamic Hypothesis



Suggested Refinements to the Raytheon Model

Over the course of the two-day SRMN meeting, participants explored the model's structure, feedback loops, and underlying research base in the K-12 and higher education domains. They drew on their expertise and experience with STEM education and research to suggest refinements to the model. The individual recommendations are too numerous to chronicle here, but the most commonly mentioned recommendations included

- Treat Student Interest and STEM Proficiency Separately
- Redefine "STEM-Capable Teacher"
- Enhance the Elementary School Portion of the Model
- Explore the Influence of Non-Teacher Related Factors
- Focus on the Quality of the Higher Education Experience
- Add Two-Year Institutions as an Entry Point into the STEM Pipeline
- Include Multiple Pathways to Becoming a STEM-Capable Teacher
- Examine Teacher Attrition in Greater Depth

Treat STEM Interest and Proficiency Separately. In the K-12 portion of the model, "STEM-interested" is equated with mathematics proficiency, as measured by NAEP. Participants pointed out a tautology in this construction: any improvement in test scores is, by definition, an increase in student interest. Because student interest is the only driver of STEM persistence in the current model, any increase in math proficiency therefore results directly in greater persistence. Participants recommended creating independent definitions for student interest and proficiency and examining the various factors that might influence students' interest in STEM at all levels of the K-16 education system.

Redefine "STEM-Capable Teacher." The term "STEM-capable teachers" is equated with improving student proficiency in mathematics, and teacher content knowledge is given the most weight in increasing student proficiency. Participants noted, however, that teacher capability is shaped by more than content knowledge. They identified several teacher-related factors that influence student interest and proficiency in STEM, including

- pedagogical skills;
- an understanding of developmental needs;
- enthusiasm for the subject matter;
- cultural fit with students.

Participants agreed that although the literature identifies characteristics of a "good teacher," there is no clear understanding of the relative importance of the myriad characteristics that constitute a good teacher. They suggested that it might be productive to develop a common definition of the components of a capable teacher. In this way, teacher capability might be defined as a latent variable with multiple indices such as "qualified," "certified," and "capable" that could be explored with the model.

Enhance the Elementary School Portion of the Model. Because of the lack of NAEP data before grade 4, the model developers adopted a representation of elementary education that has two broad segments: one for grades K-4 and another for grades 5-6. The secondary segment contains one band for grades 7-8 and individual bands for grades 9, 10, 11, and 12. Participants discussed the large and documented effect of non-STEM capable teachers in elementary school, even before grade 4, and suggested breaking the elementary school data into more discrete grade-level bands to better capture the early points at which interest and proficiency might be influenced. They also suggested including research that focuses on the relationship of teacher gender and ethnicity to students' STEM interest and proficiency.

Explore the Influence of Non-Teacher Related Factors. At the K-12 level, the Raytheon model represents in-school factors, with teacher quality as the primary driver of students' STEM proficiency. At the K-12 and postsecondary levels, participants identified several additional factors that influence STEM interest and proficiency that, if included, would enhance the model. Some of these factors include:

- **Out-of-school time for K-12 students.** After-school programs are becoming an increasingly common way to provide students with hands-on science experiences, and the body of research on those programs is growing. The influence of out-of-school programs on STEM interest, proficiency, and persistence is an important area for inclusion in the next version of the model.
- **K-12 and postsecondary curriculum.** In elementary and middle school, the nature of the science and mathematics curriculum—including interdisciplinary learning, project-based learning, and career-awareness activities—can greatly affect students' interest in STEM. At the postsecondary level, introductory science courses often exert a strong influence on students' choice of a major. Including curriculum as a determinant of STEM interest in K-12 and postsecondary education would enhance the model.
- **Alternative systems of delivering K-12 and postsecondary education.** Some participants suggested exploring whether or not the educational delivery system is a significant determinant of STEM persistence. In K-12 education, different delivery systems—such as a virtual curriculum or mastery-based learning models—that reduce the number of teachers could increase the relative proportion of STEM-capable teachers. At the postsecondary level, alternative delivery systems such as virtual education might influence student persistence in STEM majors.

Focus on the Quality of the Higher Education Experience. Currently, the postsecondary portion of the model largely focuses on student supports such as bridge programs and social networking. Participants identified several additional influences on student interest and success in STEM during the postsecondary years, including

- the nature of instruction;
- faculty motivation to teach;
- curriculum alignment with labor market needs;
- a supportive campus environment;
- access to professors;
- research and work experiences.

Participants recommended adding a constellation of feedback loops that would model multiple dimensions of the postsecondary experience.

Add Two-Year Institutions as an Entry Point into the STEM Pipeline. The model assumes a straight progression from high school into four-year institutions. Because not all students enter four-year institutions directly from high school, participants suggested adding two-year institutions of higher education to the model. In this way, they said, the model could capture the real-world phenomenon of multiple entry points into the STEM system.

Include Multiple Pathways to Becoming a STEM-Capable Teacher. In the model, the STEM-capable teacher supply comes from the postsecondary STEM-interested cohort (which includes only those students who enter postsecondary education as STEM majors or education majors related to STEM). As they explored the model, participants wondered whether someone who is not interested in STEM in college could come back as a capable STEM teacher. They decided it was possible and recommended that the model include a feedback loop on alternative certification and other pathways to becoming a teacher.

Examine Teacher Attrition in Greater Depth. Teacher attrition is a "black box" in the Raytheon model because there is not sufficient research to identify whether teachers who leave the profession are STEM capable or not. Participants suggested exploring the factors that affect teacher recruitment and retention—and, conversely, attrition—such as dual career ladders, pay for performance, district hiring policies, and the like.

STEM Research and Modeling Network

The final half-day of the meeting at the Kauffman Foundation focused on the further development and use of the model. From the outset, Raytheon's vision has been to make the model available as an open-source tool for research. At the meeting, BHEF and OSU presented a conceptual design for this transition and for the networked community that can form around it—the STEM Research and Modeling Network (SRMN).

That the "S" in SRMN stands for "STEM" rather than "system" is important: BHEF and OSU envision a community sharing a diverse array of quantitative and predictive modeling tools, applying them to the key questions and persistent problems in STEM education, and stimulating further work through rich collaborations. In this vision, the Raytheon system dynamics model is, eventually, only one of the community's tools.

The approach is anchored in well-established open-source principles and guided by a number of examples of open-innovation practices, including the University of Wisconsin's "Octave" open-source computational software and user community.

"From the outset, Raytheon's vision has been to make the model available as an open-source tool for research."

Guiding Principles

Networks are most effective when participants share common motivations, values and guiding principles. As a group, the meeting attendees described characteristics that should shape the SRMN, including

- motivated to improve education for all students;
- grounded in real-world experience, data, and practical knowledge;
- committed to translating knowledge into action (i.e., policy-relevant and linked to research);
- devoted to fostering a rich collaboration around rigorous modeling, research, practice, and policy;
- dedicated to fostering and sustaining an inclusive community of users, researchers, and practitioners;
- committed to using open innovation and open source techniques;
- willing to embrace predictive research methods and tools.

These principles constitute the charter for an open-innovation network of diverse stakeholders who will use the model as a starting point for developing a common set of STEM education and research priorities.

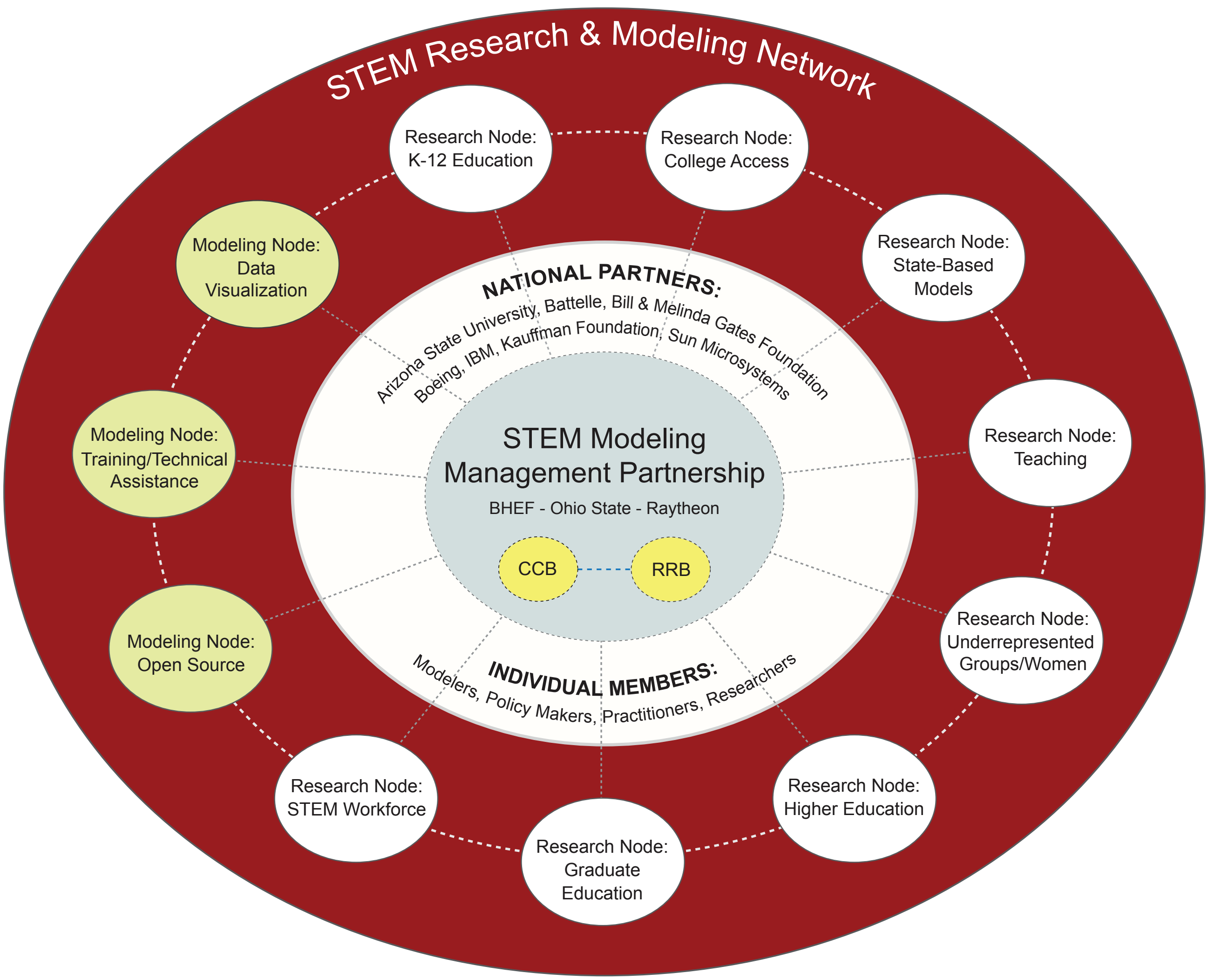
Emerging Organizational Structure

Figure 3 depicts the notional elements of the SRMN, including current and future areas of activity. The initial core of the network is centered around the Raytheon model. The System Model Management Partnership (SMMP) is being formed to steward the model. Among other things, the SMMP will

- ensure that the model can be easily accessed by users;
- maintain it in a known and stable configuration;
- address user-suggested changes, from bug fixes to research-driven improvements.

Two entities central to these duties are the Configuration Control Board (CCB in Figure 3) and Research Review Board (RRB), which will oversee technical and research-based changes to the model. Surrounding the SMMP is the set of partners and users that constitute the SRMN, i.e. organizations and individuals that are actively supporting the model and fostering innovation and research within the network. The research and modeling nodes in the graphic below are merely to suggest the types of sub-groups that may emerge.

Figure 3: Proposed Structure of SRMN



Conclusion

Participants reported that they left the meeting with an appreciation for the Raytheon model's potential to aid decision making, influence policy, and inform the STEM education research agenda. During the meeting, they combined their newfound understanding of the model with their expertise about STEM education to identify several critical changes to the model. After the meeting, Raytheon, OSU, and BHEF began undertaking some of those changes in anticipation of transitioning the model to open source in summer 2009. Reflecting the input of the meeting participants, the next version of the model will include separate flow paths for student interest and proficiency. Other developments include a user interface that is designed around pressing policy questions related to STEM persistence and the STEM teacher workforce.

Call to the Community

On a post-meeting survey, participants expressed a strong desire to continue their involvement with the SRMN; use the model and the ideas generated through the network to inform their research, practice, or organizational strategies; and develop a research agenda for STEM education. To foster continued involvement in these and other areas, BHEF has created an SRMN Web site and established an interactive electronic platform for the SRMN with Google Groups. BHEF has used these platforms to ask SRMN members to identify research studies that should be included in the model and to make suggestions for enhancing the SRMN community itself.

In the spirit of open innovation, the SRMN welcomes all who are interested. Visit ***www.STEMnetwork.org*** *for more information about the SRMN and to join the SRMN Google Group.*

STEM Research & Modeling Network Meeting Attendees

Michael Allen, Principal, Allen Education, LLC

Eleanor Babco, CGS Consultant; Associate Program Director, Professional Master's Initiatives, Council of Graduate Schools

Angela Baber, Senior Policy Analyst, STEM Education Division, National Governors Association Center for Best Practices

Constance Barsky, Science Initiatives Administrator, Ohio Department of Education

Raymond Bartlett, Consultant, Teaching Institute for Excellence in STEM (TIES)

John Branam, Director of Programs, Grantmakers for Education

Margaret Carruthers, Associate Director, Reading and Science, Words & Numbers

Annalies Corbin, Executive Director, PAST Foundation

Eilene Cross, Education Consultant, California Council on Science and Technology (CCST)

Kathleen Dalen, Vice President, PREP-KC

Joseph Fiksel, Executive Director, Center for Resilience, The Ohio State University

Brian Fitzgerald, Executive Director, Business-Higher Education Forum

Lisa Frehill, Executive Director, Commission on Professionals in Science & Technology

Tom Gall, Staff Software Engineer, IBM Corporation

Tim Gallimore, Assistant Commissioner, Missouri Department of Higher Education

Howard Gobstein, Co-Director, Science & Mathematics Teacher Imperative; Vice President, Research & Science Policy, NASULGC

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Merrilea Mayo, Director, Future of Learning Initiatives, Kauffman Foundation

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Margo Quiriconi, Director of Research & Policy, Kauffman Foundation

Jay Ramanathan, Director of Research, Collaborative for Enterprise Transformation & Innovation, The Ohio State University

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Alex Sanchez, Senior Principal Systems Engineer, Raytheon Company

James Sconing, Director, Statistical Research Department, ACT

Kathy Sullivan, Director, Battelle Center for Mathematics & Science Education Policy, The Ohio State University

Brian Wells, Raytheon Chief Systems Engineer, Raytheon Company

Kristine Wilcox, Strategic Initiatives Officer, Education, Arizona State University Foundation

John Winn, Chief Program Officer, National Math and Science Initiative

Brenda Wojnowski, Senior Program Officer, Texas High School Project

STEM Research & Modeling Network Meeting Agenda

Ewing Marion Kauffman Foundation • November 13-14, 2008

Thursday, November 13

7:45 AM Bus Departs Intercontinental Hotel for Kauffman Foundation

8:00 AM Breakfast and Registration

8:30 AM Welcome (Margo Quiriconi, Kauffman Foundation)

8:45 AM Opening Remarks (Brian Fitzgerald, BHEF and Kathy Sullivan, Ohio State University)

9:00 AM Agenda Overview (Robert Kronley, Kronley Associates)

9:15 AM Introduction to Predictive Models (Alex Sanchez, Raytheon)

Session Description: This session will demonstrate the power of modeling in other social science fields to build among participants a shared understanding of how models are developed, the different types of models, their limitations, and their potential uses.

9:45 AM Break

10:00 AM Modeling STEM Education (Brian Wells and Alex Sanchez, Raytheon)

Session Description: During this session, Brian Wells and Alex Sanchez will demonstrate the STEM education model they have developed and lead participants through a high-level review of the key variables, data, and assumptions that drive the STEM model.

11:45 AM Morning Wrap-up (Robert Kronley)

12:00 PM Lunch

Participants will have the opportunity to continue discussions from the morning session and ask questions of Brian Wells and Alex Sanchez to solidify and deepen their understanding of the model.

1:30 PM Breakout Sessions (Robert Kronley will facilitate)

Session Description: Participants will break into five working groups to examine a key model segment in greater detail. Each group will assess the major assumptions used to construct the model and learn how new data can be incorporated to improve the model.

3:30 PM Plenary: Working Group Synthesis

Each working group will share its findings for discussion among the larger group.

5:00 PM Adjourn

6:30 PM Reception

7:15 PM Dinner

Session Description: Participants will select from among a number of table conversations to explore how modeling can contribute to advancing a particular aspect of STEM education research and policy. Such topics may include the STEM teacher workforce, developing state-based models, STEM disciplines, industry workforce needs, K-12 STEM curriculum and instruction, STEM undergraduate or graduate education, or other topics that participants may propose.

Friday, November 14

7:45 AM Bus Departs Intercontinental Hotel for Kauffman Foundation

8:00 AM Breakfast

8:30 AM Opening Remarks and Reporting Out from Dinner Conversations (Robert Kronley)

9:00 AM Using Open Innovation and Open Source in STEM Research and Modeling (Tom Gall, IBM and George Blaha, Raytheon)

Session Description: Participants will hear from experts on open innovation and open source processes who will help attendees better understand these processes and how they have been applied in a range of contexts, including the development of the Raytheon model. Then, panelists and participants will engage in a discussion about how these concepts could be used to build a community of researchers and users who will use open innovation to promote the adoption and use of multi-method modeling to strengthen STEM education.

10:30 AM Break

10:45 AM Launching the STEM Research & Modeling Network

Session Description: Participants will be asked to help identify next steps in establishing the core cadre of SRMN partners/affiliates and launching the open-source collaborative.

12:00 PM Working Lunch

Wrap-up, including summary of major outcomes and next steps.

1:30 PM Adjourn

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