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The center for STEM Education and Outreach at James Madison University: A case study for using system dynamics and the balanced scorecard to perform strategic planning

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The Center for STEM Education and Outreach at James Madison University: *A case Study for Using System Dynamics and the Balanced Scorecard to perform Strategic Planning*

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Abstract

Concern that the U.S. education system is unsuccessful in keeping the United States a competitive nation in global talent race has pushed policymakers to plan for improving science, technology, engineering, and mathematics (STEM) education in the country. These are the disciplines that need to be fostered to supply the United States with talented graduates that can keep its economy competitive. Many major public and private organizations are investing significant resources to address this challenge. The Center for STEM Education and Outreach at James Madison University is among the parties working on promoting STEM education in the State of Virginia through improving teaching and curriculum quality. This thesis investigated the use of system dynamics and the Balanced Scorecard to help the Center's leadership develop and improve strategies to achieve the Center's goals. Four meetings were conducted with the Center's leadership and a qualitative system dynamics model and a BSC Strategy Map were developed during these meetings. Questions were sent to each member of the Center's leadership focused on the insight and benefits obtained from the whole process. The answers indicated that the process gave the Center's leadership the opportunity to discuss the Center's main focus and direction. This study was compared to the SRMN national model and the results showed alignment between the two works.

Chapter One

1.1 Introduction

Concern that the U.S. education system is unsuccessful in keeping the United States a competitive nation in global talent race has pushed policymakers to plan for improving science, technology, engineering, and mathematics (STEM) education in the country (STEM Education Coalition, 2010). These are the disciplines that need to be fostered to supply the United States with talented graduates that can keep its economy competitive. Many major public and private organizations are investing significant resources to address this challenge (Business Higher Education Forum, 2010). The Center for STEM Education and Outreach at James Madison University is among the parties working on promoting STEM education in the State of Virginia through improving teaching and curriculum quality. This thesis investigates the use of system dynamics and the Balanced Scorecard to help the Center's leadership develop and improve strategies to achieve the Center's goals (http://www.jmu.edu/stem/outreach).

Traditional strategic planning and control systems were designed and based solely to impact financial indicators and measures (Kaplan & Norton, 1992, 1996). In the case of a non-profit enterprise, like JMU's Center for STEM Education and Outreach, financial goals may not seem relevant. However, it is often the case in such organizations that such indicators as the annual income from grants play a similar role. Also, organizations whose activities are aimed and development of people are often tempted to limit their attention to short-term "countable" measures such as #participants in workshops, #workhops held, etc. Hence, whether dealing with for-profit businesses or non-profit organizations, a more balanced set of indicators for measuring progress toward strategic goals is needed. Conventional strategic planning and control systems do not effectively do this because they do not enable mangers and decision-makers to effectively communicate to stakeholders the value creation process they want to foster through their organizations' strategy. Failure to communicate the organizational strategy to managers and employees at different levels of the organization hierarchy might create misalignment between the strategic decisions and daily operations (Bianchi & Montemaggiore, 2008). In fact, financial or other short-term indictors do not provide a complete reflection of the organization's directions and goals if they are not accompanied with other measures (Bianchi & Montemaggiore, 2008) (Kaplan & Norton, 1992). One of the drawbacks of using only financial indicators is that managers will make decisions to seek short-term goals rather than long term growth. Another weakness associated with designing and implementing strategy based on only such measures is the difficulty in measuring nonfinancial goals and intangible measures (Kaplan & Norton, 1996).

Hence, to pursue competitiveness and success, organizations need effective strategy design and planning tools that allow them take into account not only financial variables and measures but also intangible strategic variables (Kaplan & Norton, 1996). Yet, a proper strategic planning and design process requires a focus on the strategic, critical, key indicators of the organization's effectiveness and efficiency (Bianchi & Montemaggiore, 2008).

1.2 The Balanced Scorecard and strategic planning

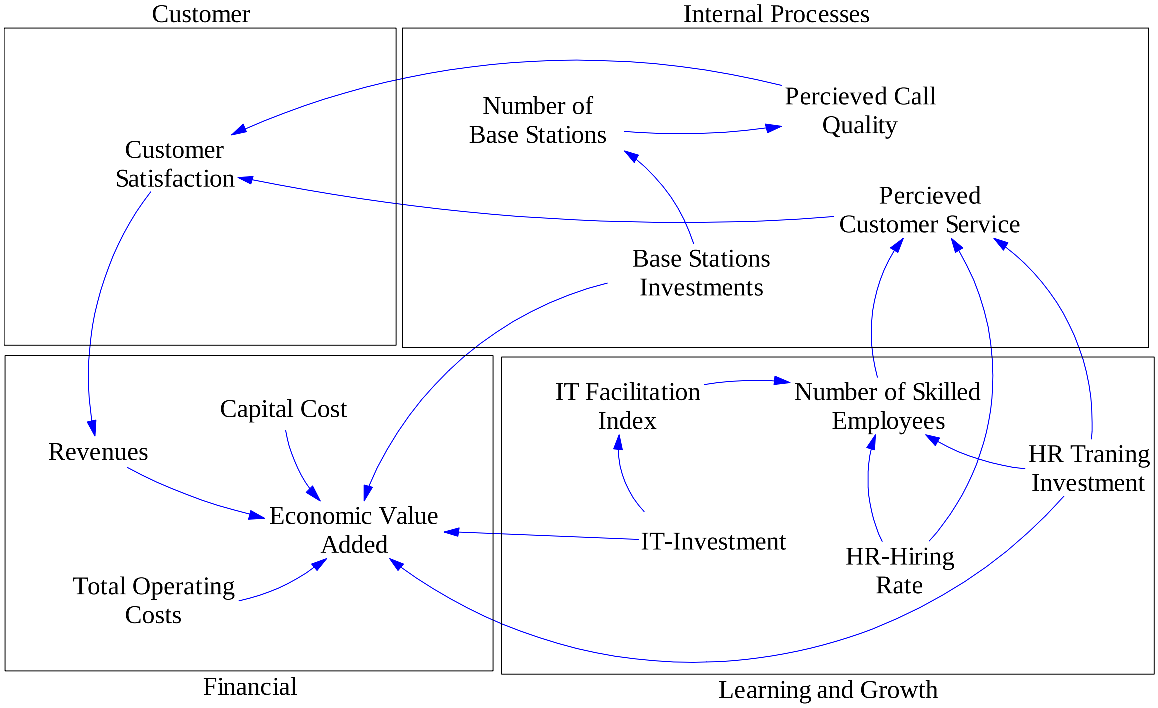
Managing tasks and goals requires measuring the progress towards achieving these tasks and goals. If companies and organizations were to thrive in their environment, they must use measurement systems that reflect their strategies and capabilities. One of the most successful performance management platforms is the Balanced Scorecard (BSC) (Akkermans & Oorscht, 2005). Introduced by Robert Kaplan and David Norton in 1992, the BSC provides decision-makers with a platform to identify performance indicators that are relevant to the organization's mission and strategy (Kaplan & Norton, 1996, 2004, 2000). The use of the BSC has acquired wide popularity among private and public organizations. Today, many organizations are using the BSC methodology to define, implement, and manage strategy and recent surveys confirmed that BSC was the most popular performance management system, adopted by over 40 percent of organizations around the world (Capelo & Dias, 2009).

The BSC provides a language to communicate and share mission and strategy. This approach is also an excellent method to send the message to the organization's stakeholders about the drivers of current and future success (Kaplan & Norton, 1996, 2004, 2000). Moreover, the BSC not only provides decision-makers with a group of measures; it provides a "handful of strategically critical measures in one report" (Saghaei & Ghasemi, 2009). The BSC balances between the financial, short term, "countable" measures and non-financial, intangible measures. The approach also balances between performance drivers (lead indicators) and outcome measures (lag indicators). These measures are organized in perspectives or levels and these perspectives depend on the type of the organization (Akkermans & Oorscht, 2005).

To develop an effective BSC, Kaplan and Norton suggest it is very important that decision-makers grasp the causal relationship between the performance drivers (lead indicators) and the organization's strategic objectives or outcomes (lag indicators) (Kaplan & Norton, 2000). Furthermore, it has been proven that recognizing the causal relationships between the strategic measures of any organization is crucial in strategic planning (Saghaei & Ghasemi, 2009). Kaplan and Norton introduced Strategy Maps in 2004 (Kaplan & Norton, 2004). The Strategy Map enables decision-makers at different levels in the organizational hierarchy to specify scorecards that reflect the strategy by identifying and highlighting the cause-and-effect relationships between these scorecards or measures (Saghaei & Ghasemi, 2009).

When Kaplan and Norton first introduced the concept of the BSC, they suggested that the measures must be organized in four perspectives: learning and growth, internal processes, customer, and financial (Kaplan & Norton 1992). Carlos Capelo and Joao Dias developed a Strategy Map for a telecommunication company to help the management team to identify strategic measures and the required investments they should make to improve the corporate performance (See Fig. 1.1).

Figure 1.1: Strategy Map Example
A Strategy Map shows how IT-investment, HR-Hiring, and Base station investment can affect strategic measures for a telecommunications organization such as Custom Service, Customer Satisfaction and, the Economic Value added
Source: Capelo & Dias, 2009



All the measures and actions were organized with the four perspectives framework. Capelo and Dias demonstrated how investment in information technology, hiring rate, and building new base stations can affect the customer service and call quality and how these impact customer satisfaction which affect the economic value added (EVA). This map is a combination of the strategic actions required to achieve the goals and the strategic measures that management need to monitor to track progress (Capelo & Dias, 2009).

Later, Kaplan and Norton explained that the perspectives depend on the organization's nature and type. They explained that if the organization was, for example, a non-profit organization, the perspectives may be different from the ones mentioned above (Kaplan & Norton, 2004).

1.3 The Criticism of the Balanced Scorecard

The main advantage of the BSC is concentrating organizations' efforts on a few strategic, well-balanced variables. It is also a significant bridge between different fields within the organizations, both financial and nonfinancial (Akkermans & Oorscht, 2005). Yet, it is very important that decision-makers and strategists make sure that the few selected strategic variables are the right ones that reflect the organization's strategy (Kaplan & Norton, 1992, 1996, 2004). They also must frequently reexamine their processes/systems to see if other variables or measures need to be added. The alignment between the variables must be identified and tested and the causal relationships between the critical measures or variables should be identified (Tan et al, 2004). These causal chains will eventually be represented as a diagram that people can use to modify and externalize their mental models or understandings of the system and enrich these by sharing them (Akkermans & Oorscht, 2005).

Some researchers have reported a number of weaknesses or disadvantages associated with the use of the BSC. For example, if the organization has to focus on a small number of strategic variables, how can it be sure that these are the right variables and they are relevant to the overall strategy? And if this approach facilitates communication between different fields and levels within the organization, how could it be managed effectively? (Akkermans & Oorscht, 2005)

Research shows that the BSC framework does not provide a mechanism for maintaining the relevance of defined measures. Some researchers argue that the BSC can lead provide too many measures to be practically managed (Neely et al, 2005). Finally, the causal relationships between the measures addressed in BSC Strategy Map are unidirectional rather than being bidirectional. Hence, BSC does not adequately integrate between the top level strategic scorecard, and operational-level measures (Hudsen et al, 2001).

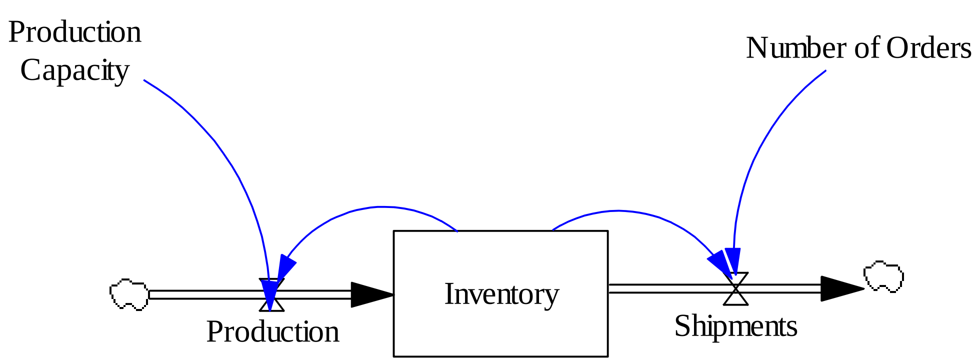
1.4 Overcoming BSC limitations using System dynamics

System dynamics is a methodology for addressing problems whose origins are found in the behavior of some underlying complex systems (Ritchie-Dunham & Robino, 2001). It was created by Professor Jay Forrester during the mid-1950s. At the Massachusetts Institute of Technology (MIT), Professor Forrester tried to apply his background in science and engineering to solve problem of complex social systems. After years of research, he discovered that the biggest hindrance to progress comes from management policy and the accompanying social dynamics within the organization (http://www.systemdynamics.org).

It was Forrester's involvement with General Electric (GE) to solve an employment problem that made him think about applying engineering concepts to solve managerial issues. Using stock-flow-feedback structure, Forrester demonstrated how the internal structure of the firm led to that problem and not external forces. This stock-flow-feedback, which was performed by hand not computers, was the beginning of system dynamics simulation and modeling (http://www.systemdynamics.org).

Stock-Flow diagramming is a method to represent how a given system works. Stocks are accumulations. They characterize the state of the system and generate the information upon which the decisions and actions are made. Flows represent the rate at which the stocks vary over time. The rate of the flow could depend on the value of the stock or other factors. In stock-flow diagramming, stocks are represented by rectangles while flows are represented by pipes with arrows. The direction of the arrow depends whether it is an inflow or outflow. The rate of the flow is governed by a valve (Sterman, 2000). For example, a firm's inventory is a stock, the value of which depends on the production and shipments. The inventories will build up if production rate is higher than the rate at which products are shipped. However, if the firm ships products more than it produces, the inventories will deplete (See Fig 1.2).

Figure 2.1: Stock-Flow Diagram Example
An example Stock-Flow diagram shows a firm's inventory (stock) and factors that impact the value of the inventory by impacting the flow of products into and out of the system.
Source: Sterman, 2000



System dynamics provides tools for understanding the problem from a system-wide perspective and for evaluating the system-wide impacts of policies for addressing the problem. System dynamics also facilitates the understanding of the unintended consequences of policies that arise from the dynamic complexity of the system in hand. System dynamics has proven beneficial in four aspects of managerial decision making (Ritchie-Dunham & Robino, 2001):

- Comprehending the environments in which the organization operates.
- Sharing observations and experiences related to the organization and its complex environment
- Thinking about, understanding, and testing the dynamic behavior of the organization over time
- Formulating effective strategies and actions for achieving the organization's goals

Systems dynamics methodology can be enormously beneficial in implementing and executing better strategy by identifying the strategic variables. The strategic variables are fundamental resources, processes, and performance measures. Understanding the causal relationships between these variables and the way they affect the performance of the organization and building is crucial to design effective strategies. The diagramming and simulation tools that system dynamics provides are powerful tools that can aid leaders to better understand problems and their causes, anticipate the outcomes of alternative policies and actions (Lyneis, 1999).

Some researchers have suggested system dynamics as a powerful approach to overcome and improve the limitations to current BSC theory (Akkermans & Oorscht, 2002, 2005) (Ritchie-Dunham & Rabbino, 2001) (Bianchi & Montemaggiore, 2008). System dynamics is a well developed and tested systems thinking methodology and language. It helps individuals to share a common understanding of the system under study. Analyzing systems using this approach provides insights on the causal relationships between the system's variables and the underlying structure which governs the behavior of the system (Akkermans & Oorscht, 2005).

Capelo and Dias introduced a theoretical model that explains the formulation of the BSC Strategy Map using system dynamics and feedback learning perspectives (Capelo & Dias, 2009). James Ritchie-Dunham and Hal Rabbino wrote in their book "Managing from Clarity: Identifying, Aligning and Leveraging Strategic Resources" that the balanced scorecard can be captured and designed using a system dynamics model. They mentioned that decision-makers will be able to identify what resources they need to create value and move the system in the desired direction. And since system dynamics provides a very good mechanism to understand the structure of the system under study, executives will understand how the enabling resources (lead indicators) and performance drivers (lag indicators) are linked causally to each other and the organization strategy (Ritchie-Dunham & Rabbino, 2001). Furthermore, Bianchi and Montemaggiore argued that the use of the dynamic BSC can significantly improve strategic planning process (Bianchi & Montemaggiore, 2005).

1.5 Ritchie-Dunham/Hal Rabbino and Akkerman/Oorschot Methodologies

A number of researchers have introduced methodologies and approaches of using system dynamics and the BSC in strategic planning and organizational learning. They have discussed how system dynamics can add value to the current BSC theory and developed methodologies for using these two management tools to formulate strategies.

James Ritchie-Dunham and Hal Rabbino introduced the Managing from Clarity methodology in 2001. This five-step methodology helps leaders to understand the organizations they lead, share this understanding (mental model) with internal and external stakeholders, and identify the required actions to move the organization in the desired direction. According to Ritchie-Dunham and Rabbino, managing from clarity adds value to the BSC theory. The methodology highlights the effect of each participant or stakeholder on the organization’s strategy and goals which will create a balanced structure that meets the requirements of all stakeholders. The framework also offers a balance between tangible and intangible measures or financial and non-financial variables (Ritchie-Dunham & Rabbino, 2001).

The first step of this methodology focuses on creating a map of the organization’s overall goals, resources, actions, structure, and participants (stakeholders). The causal relationships between all the variables of the system need to be identified and presented qualitatively using causal loop diagramming (CLD). CLD is a tool for articulating the cause and effect relationship between the system’s variables (Sterman, 2000). Next, the organization should know how to build up, maintain, and utilize the critical strategic resources and what actions provide the most leverage in developing these resources. This can be achieved using stock-flow modeling of system dynamics which can enable strategists to understand what can affect these strategic resources and how they behave over time under different actions. The third step would be integrating the strategic resources in a single quantified model to understand the dynamic behavior of the whole organization. The fourth step will involve scenario planning and strategic foresight during which the assumptions made in the first step are examined. In the final step, a learning interface will be built to communicate the logic and drivers behind the desired actions to the whole organization in a highly effective, self-teaching way (Ritchie-Dunham & Rabbino, 2001).

The other methodology that uses both system dynamics and the BSC to perform strategic planning is a two-stage methodology introduced by Akkerman and Oorschot. The methodology's first stage focuses on capturing and translating the mental models of the management team using causal loop diagramming (CLD). From this diagram, the key performance indicators (KPIs) or the strategic measures are distilled and assigned targets. These measures represent the preliminary BSC. The causal loop diagram will help managers and decision-makers to find the causal relations between the BSC to build the Strategy Map (Akkerman & Oorschot, 2005).

The next stage is translating the causal loop diagram into a quantified simulation model. The model will be calibrated and built using the organization's key data. The implicit assumptions about the dynamic behavior of the preliminary BSC will be tested. This stage is a way to test the causality between the preliminary list of strategic variables. It will also help the managers to make sure that these variables are really strategic by testing their effect on the ultimate strategic objectives of the organization (Akkerman & Oorschot, 2005).

Each of those methodologies makes important, but complimentary contributions to the strategic planning process. . Ritchie-Dunham and Rabbino's methodology makes it explicit that the organization must identify its goals from the very beginning because these goals are the main reason why the organization exists and every action must be aligned with these goals. They also emphasize that organizations must identify the required resources which they call "strategic resources" in order to achieve their goals. This is not explicitly mentioned in Akkerman's and Oorschot's methodology. Akkerman's and Oorschot's methodology, on the other hand, starts with explicitly identifying a preliminary list of strategic performance indicators. This list, then, will be tested and refined using system dynamics. This is important because it specifies a preliminary scope for the strategic planning process. As a result of these complementary strengths, the methodology used in this thesis includes elements from both approaches.

1.6 Case Study for the Thesis: The JMU Center for STEM Education and Outreach and efforts to increase STEM graduates from Virginia Colleges and Universities

As mentioned in the introduction, policymakers in the United States have realized that making advances and progress in science and engineering is essential to have a sustainable national security and economic growth. The STEM Education Coalition states that the available data show that U.S. demand for technology scientists and engineers will increase at four times the rate for all other occupations during the next decade (STEM Education Coalition, 2010). However, the data also show that today's high school students are not performing well in math and science, and fewer of them are pursuing degrees in technical fields. This challenge requires immediate actions and policies aiming to foster science, technology, engineering and math (STEM) education in the United States (Wells et al) (STEM Education Coalition, 2010).

The 2007 Trends in International Mathematics and Science Study (TIMSS) report was released in mid-December 2008 and the results for U.S. students were mixed. U.S. average math scores improved a little since 1995. Science scores, however, stagnated. Moreover, major European and Asian nations continues to outperform the U.S. in this contest. The U.S. 2007 eighth grade math score average (508) was higher than the TIMSS scale average of 500 and the 1995 math average of 492. And the U.S. 2007 eighth grade science average of 520 was higher than the 1995 average of 513. The U.S. 2007 forth grade math score average (529) was higher than the TIMSS scale average of 500 and the 1995 math average of 518. 2007 U.S. forth grade science average (539) was higher than TIMSS scale average of 500 but lower than 1995 average of 542 TIMSS (National Center for Education Statistics, 2008). Furthermore, the U.S. students are outperformed by students in other industrialized nations in STEM critical thinking skills according to the Program for International Student Assessment (National Science Board, 2007).

The STEM Education Coalition releases an annual K-12 STEM Education report. This report provides state-level data about the latest education score for science and math. The coalition released a 2010 version for the State of Virginia which also compares STEM related measures from each state with the same indicators for the nation (See Table 1). The report also indicates that “Interest in STEM Education is declining and most students are not adequately prepared to succeed in college-level coursework” (STEM Education Coalition, 2010).

Table 2.1: Latest Educational Scores for Science and Math
Virginia's K-12 STEM Education Report Card 2010, Source: www.stemedcoalition.or

RANK	**NAEP Scores (National Assessment for Educational Progress)**	State Average	Nation Average
19	2009 Grade 8 Mathematics Average Score	286	282
17	2009 Percentage "At or Above Proficiency" in Math	36%	31%
13	2005 Grade 8 Science Average Score	155	147
	ACT Scores 2009		
25	Virginia's 2009 Average ACT Science Score	21.4	20.9
21	Virginia's 2009 Average ACT Math Score	21.8	21.0
39	Percentage of Graduates Taking ACT in 2009	20%	45%
	SAT © Scores & Advanced Placement (AP) percentages 20		
35	Virginia's Average Mean Score for SAT Mathematics 2009	512	515
12	Virginia's Percentage of Graduates Taking SAT Mathematics 2009	68%	46%
3	AP Math Exam Percentage of High Schoolers Taking 2007	13.4%	9.4%
6	AP Science Exam — Percentage of High Schoolers Taking 2007	11.8%	8.1%
	College Readiness Indicators: % ACT Tested Students		
21	ACT Math % of H.S. Graduates ready for College Level 2009	49%	42%
17	ACT Science % of H.S. Graduates ready for College L evel 2009	33%	28%
	Teacher Quality Indicators (K-12) 2004		
6	Percentage of Middle Level Science Teachers Certified	84%	54%
3	Percentage of Middle Level Math Teachers Certified	84%	49%
8	% of H.S. Chemistry Teachers with Main Certification in Chemistry	78%	53%

1.6.1 The Center for STEM Education and Outreach at James Madison University

The Center for STEM Education and Outreach at James Madison University has a mission to improve and promote a distinctive STEM education for all students in grades K-16 all over the State of Virginia. The Center cooperates and works with all the stakeholders, whether they are students, teachers, parents, policymakers or the general public to achieve this mission. This mission, according to the Center's official website, can be achieved by supporting excellent curriculum and professional development and sharing the many resources of JMU faculty, staff, and students with schools across Virginia (http://www.jmu.edu/stem/outreach/)

This thesis will use system dynamics and BSC approaches to help the Center to achieve its goals and track their efficacy. This task requires a thorough understanding of the variables and factors and their interrelationships affecting student progress in the STEM disciplines and how those variables relate to the goal of the JMU STEM Center. Such insights depend on understanding some of the complex interactions and feedbacks affecting student progress in the STEM disciplines. For example, the number of students interested in STEM is affected in part by the number of STEM capable teachers. However, to increase the number of STEM teachers we need more students interested in pursuing STEM college degrees. Furthermore, the availability (or paucity) of high quality STEM teachers can also impact and be impacted by other variables in the system through causal relationships that are second or third order and that may involve long delays. Such relationships and complexities must be explicitly described to guide individuals such as the leaders of the JMU STEM center who are trying to design policies and actions to promote STEM education.

1.6.2 The SRMN National STEM Planning Model

The STEM Research and Modeling Network (SRMN) is a group of researchers, policymakers, practitioners and funders from around the nation who are using system dynamics modeling to provide decision making tools for policymakers interested in improving student interest and performance in the fields of STEM. The SRMN was established through a partnership between the Business-Higher Education Forum (BHEF), Raytheon, and the Ohio State University. The main task of the SRMN was to develop a system dynamics model representing the U.S. STEM education to examine policies and ways to increase the number of STEM students. The model is an open source tool and available for researchers, policymakers, and other concerned participants (http://www.stemnetwork.org/)

The SRMN system dynamics model was constructed from four sub-systems (Business Higher Education Forum, 2010):

1- K-12 Grades: represented the progress of K-12 students from grade to grade and the factors that affect their proficiency and interest in STEM
2- College: showed the skills college students in STEM teaching majors need to develop in college to become STEM capable teachers

3- Professional: showed the represented the dynamics of STEM teaching career. It showed how certain policies can affect the number of STEM capable teachers
4- Career Selection: the dynamics of career selection and market effect on STEM teaching career

In its current embodiment, this national STEM model allows policymakers to explore policies to double the number of STEM college graduates by 2015 through changes in (1) the salary of STEM teachers, (2) STEM class size, and (3) improving the quality of the STEM teacher pool., and (4) the use of bridge and cohort programs for STEM students entering college. The results of the model and analysis of the U.S. education system showed that strategies focusing on both K-12 and higher education are vital for achieving the goal. For K-12, the results of the model showed that improving STEM teacher's quality is fundamental to increase K-12 students' interest and proficiency in STEM. The model also showed that bridge and cohort programs for STEM college student can yield "early and significant return on investment" (Business Higher Education Forum, 2010).

This research will include building a qualitative system dynamics model focused on the main concern of the Center's leadership which is STEM teaching and curriculum quality in the Sate of Virginia. The Center's leadership involvement in building that new model will lead to a more precise representation and deeper understanding of how well the center's actions will impact the national STEM education problem and how well aligned those actions are with the Center's stated goals. In this study, we will not try to test different actions and strategies, rather, the research will investigate the alignment between the Center's policies and its mission. The new model and the findings of this thesis will be compared to the SRMN model and similarities and differences between the two works will be investigated.

1.7 Research Objectives

The objectives of the study are to evaluate the utility of system dynamics to develop a BSC with the leadership of JMU's Center STEM Education and Outreach and to gain feedback from the leadership team regarding insights from the strategic planning process. The research will help answer the following questions:

1. What are the strategic goals of the STEM Center at James Madison University?
2. What critical leverage points exist that can be utilized most effectively to achieve the Center's strategic goals?
3. What are the causal relationships between these goals and resources and how they affect each other?
4. What additional insights does the use of system dynamics and the BSC provide for leading the STEM effort at JMU?
5. How much alignment is there between the National SRMN model and the BSC Strategy Map developed in this thesis

Chapter Two

2.1 The Process

As mentioned in Chapter One, the case study described in this thesis is The Center for STEM Education and Outreach at James Madison University. The Center works as a liaison to "coordinate and connect activities across JMU campus with partners in K-12 and other parties interested in STEM" (http://www.jmu.edu/stem/outreach). I worked as a facilitator to help the Center to elucidate its goals by using system dynamics and the balanced scorecard. The methodology used in this thesis consists of procedures from the two methodologies mentioned in Chapter One. Whilst the two aforementioned methodologies involve building a quantified system dynamics methods, the methodology used in this thesis's methodology focus on building a qualitative system dynamics model and a BSC Strategy Map. It is a four-stage methodology; each stage required a meeting with members of JMU STEM Education and Outreach Center. The Center's leadership consists of the following individuals:

- **Dr. Arthur Benson**
  Vice Provost, STEM and Health and Human Services

- **Dr. Robert Kolvoord**
  Co-Director, Center for STEM Education and Outreach,
  Professor, Integrated Science and Technology (also thesis co-advisor)

- **Dr. Lou Ann Lovin**, Co-Director, Center for STEM Education and Outreach
  Associate Professor, Middle, Secondary and Mathematics Education

- **Dr. Eric Pyle**, Co-Director, Center for STEM Education and Outreach,
  Associate Professor, Earth Science Education

2.1.1 Stage One: Defining Goals, Actions, and Strategic Measures of Performance and Building the Preliminary Stock-Flow Diagram

During the first stage, a one hour meeting was conducted with the Center's leadership to define the Center's goals, the required actions to achieve the stated goals, and the strategic performance indicators needed to monitor the Center's performance. The goals were defined as the ultimate objectives of the Center; they represent the main reason of the existence of the Center [Ritchie-Dunham & Rabbino]. The actions represent the Center's strategy to achieve its goals. The measures are those variables that the leadership of the Center considers to be strategic. They are considered strategic because by monitoring these variables or performance indicators, the Center's leadership will verify if they are making progress to achieve their goals and whether their strategy is successful or not (Kaplan & Norton, 1996).

The following is the list of goals, measures, and actions identified by the Center's leadership at the first meeting:

Goals

- Improving the quality of STEM teachers in the state of Virginia
- Improving the achievement (performance) and interest of high school students in STEM education in the state of Virginia

Measures

- STEM teachers attrition rate (turnover)
- Number of highly qualified STEM teachers
- Student interest in STEM (K-12)

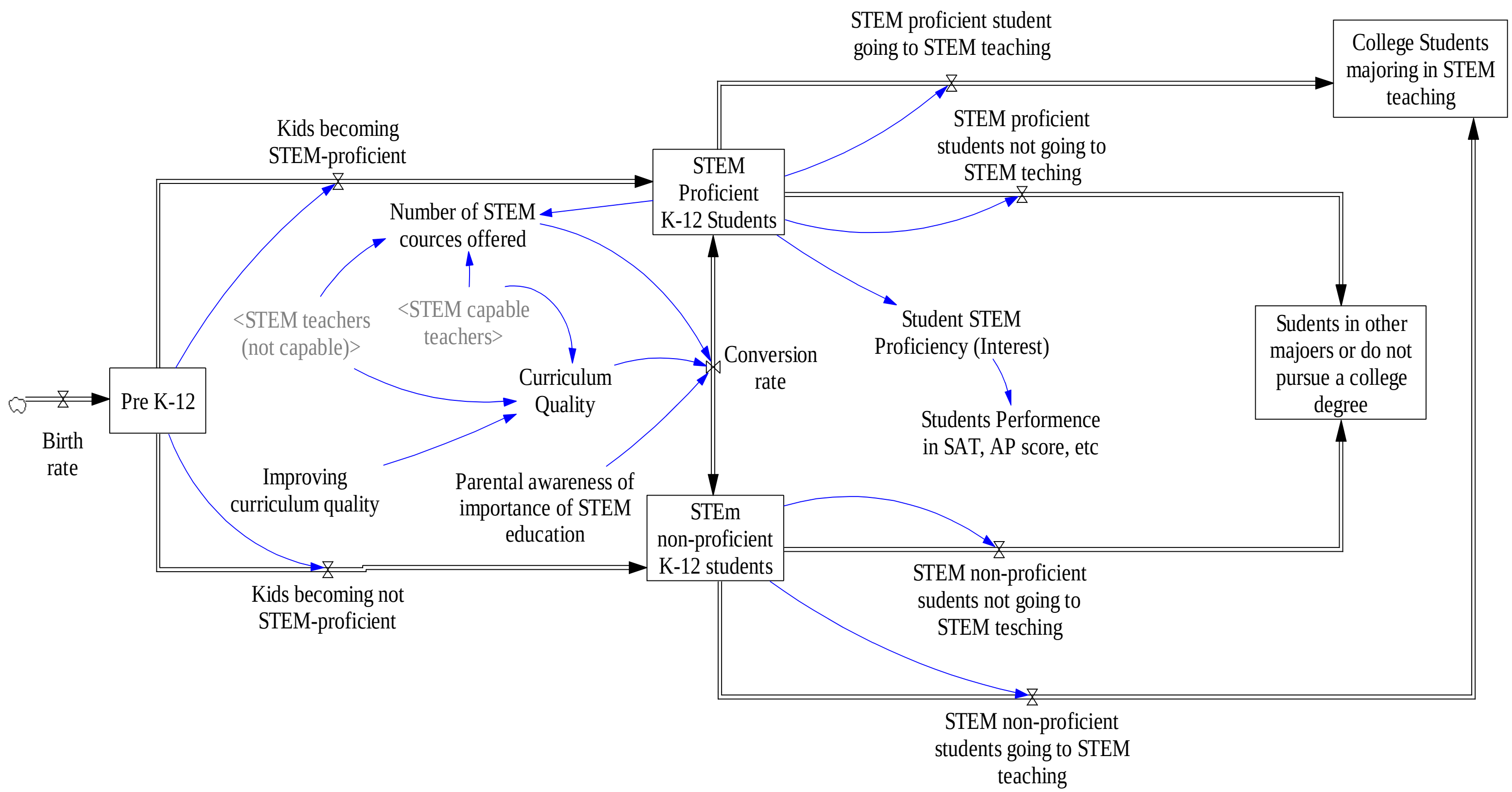
- Student performance in tests and courses such as (SAT, AP scores, etc.)
- Number of STEM courses in high school
- Quality of pedagogy – how learning opportunities are constructed/delivered
- Standards and Assessment processes adopted by the State if Virginia
- Parental understanding of importance of and support of learning (STEM)

Actions

- Improving the interaction with teachers to make them more aware of the importance of STEM education
- Improving STEM curriculum quality
- STEM teacher professional development (training)

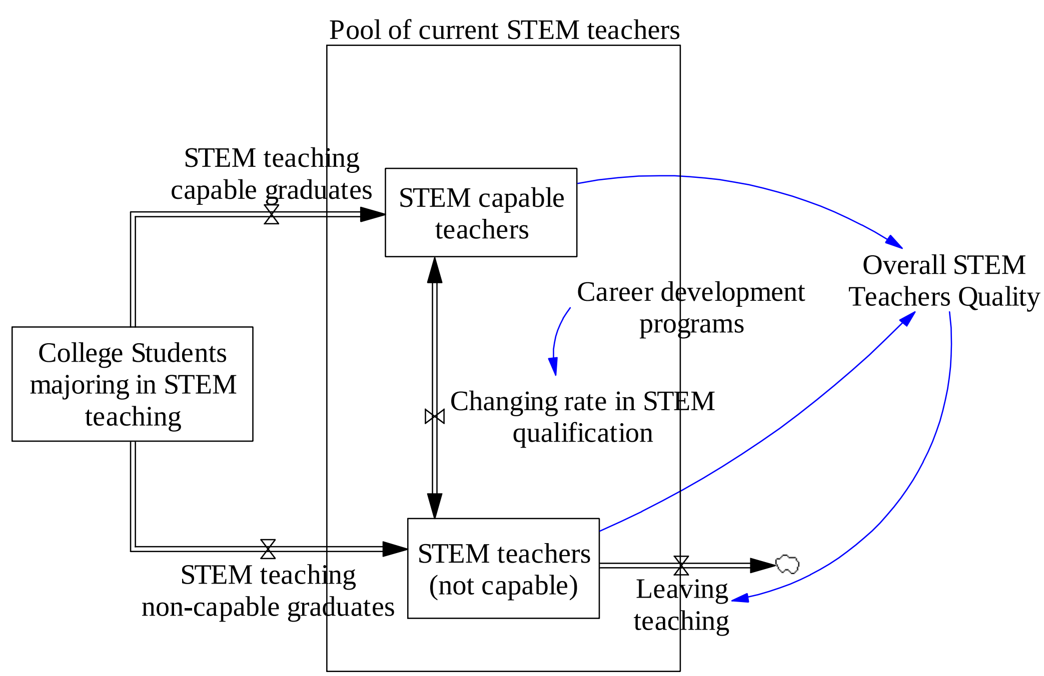
This was the preliminary list that would be modified as we progressed through the other steps. After this first meeting, an initial stock-flow diagram was developed to show the causal relationships between the factors identified in the first meeting (see Fig 2.1 a). Other variables were added to show the flow of students as they progress through K-12, into college, and post-college or post-high school careers. At first, the assumption was made that a fraction of the students entering K-12 are STEM-proficient and the rest are not. During their K-12 experience, student proficiency can change depending on several factors. According to the Center's leadership, these factors are curriculum quality, number of STEM courses offered, and parental awareness of the importance of STEM education.

Figure 2.1a: Stage One Stock Flow Diagram (first part)
The first part of the preliminary stock-flow diagram developed using the information collected during the first meeting. This diagram shows the factors that can impact K-12 students' proficiency in STEM.



As students finish their K-12 education, they either choose to major in STEM teaching, other majors, or do not choose to pursue a college degree. Of those students who majored in STEM teaching and chose a STEM teaching career, a fraction will become capable teachers and the other fraction will become STEM-not-capable teachers (See Fig. 2.1 b).Capable teachers are those who have the minimum required STEM teaching knowledge while non-incapable teachers do have this minimum required knowledge. However, teachers can move from one category to another as their teaching capabilities may improve or decline. We assumed that from the ratio of STEM-capable teachers to the total number of available STEM teachers the overall STEM teaching quality can be measured.

Fig. 2.1b: Stage One Stock-Flow diagram (second part)
The second part of the preliminary stock-flow diagram developed using the information collected during the first meeting. This diagram shows how some college students majoring in STEM teaching can become either capable or incapable teachers and where the Center can intervene to improve teaching quality which can impact the rate at which teachers leave STEM teaching. At first we assumed that the teacher might leave only if he/she is incapable STEM teacher



The teaching quality would feedback into factors that impact K-12 Students' proficiency in STEM: curriculum quality and number of STEM courses offered. The process of building the stock-flow diagram highlighted how the quality of STEM teachers can impact students' proficiency in STEM; the main concern of all the parties working on improving STEM education.

2.1.2 Stage Two: Discussing and Refining the Preliminary Stock-Flow Diagram

Another meeting was conducted to discuss and refine the stock-flow diagram developed after the first meeting. The first issue discussed in the second meeting was whether the stock-flow model was a close representation of the Center Leaderships' understanding of the system they are trying to impact. Moreover, it was agreed that every performance measure or goal that is not impacted by their actions should be eliminated. The result was a refined version of the stock-flow diagram. (See Fig. 2.2)

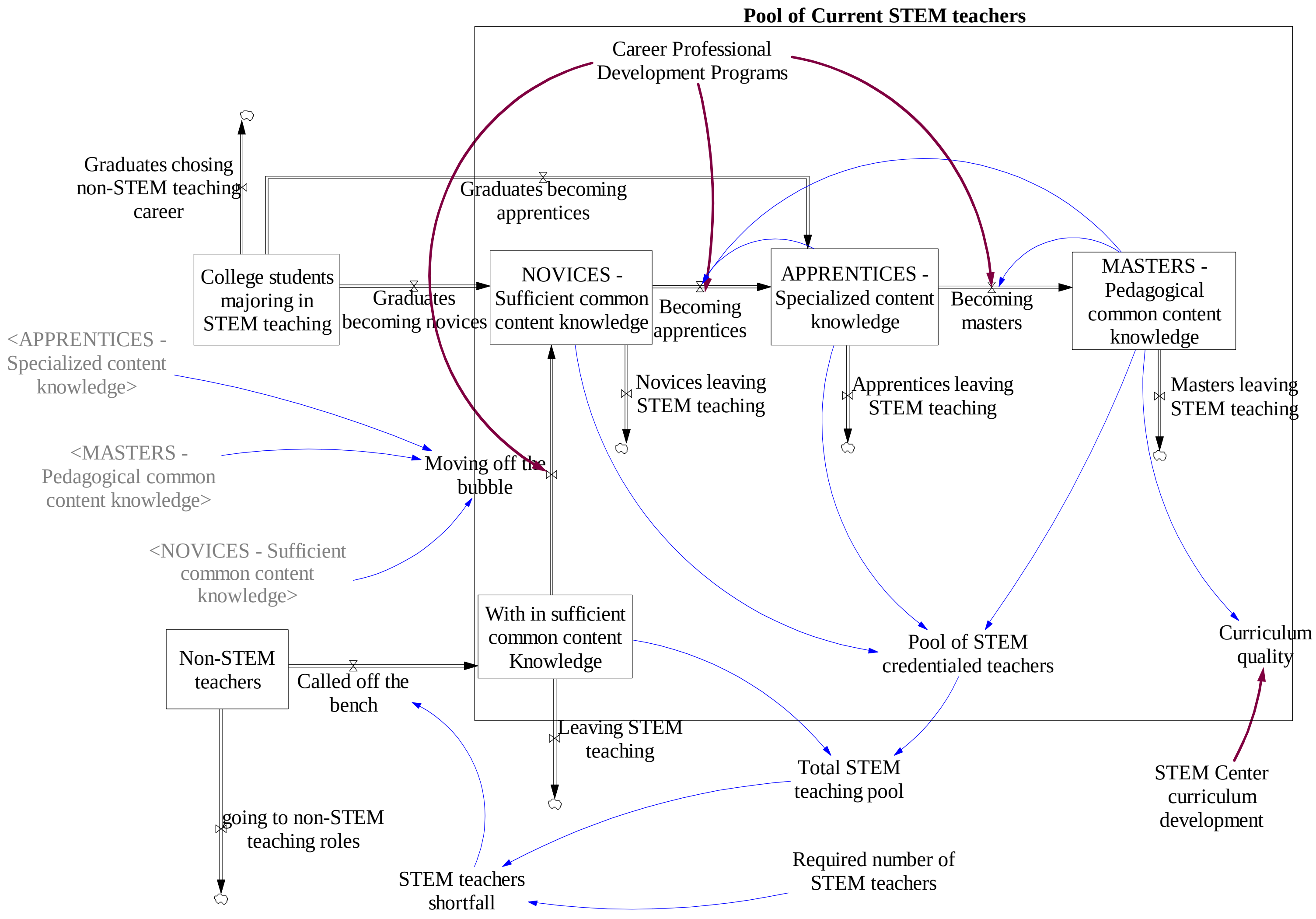
Parental awareness of the importance of STEM education was eliminated from the measures list and the stock-flow diagram because it was discovered that none of the Center's actions directly impact this measure. Since the Center's focus is on improving STEM teaching skills, they suggested that the pool of current STEM teachers should be disaggregated into three categories based on three types of teaching knowledge:

- Common Content Knowledge (CCK): This is mathematical knowledge a well-educated STEM college graduates knows.

- Specialized Content Knowledge (SCK): This is mathematical knowledge beyond what any well-educated STEM college graduate. SCK does not include knowledge of students or knowledge of teaching.
- Pedagogical Content Knowledge (PCK): This knowledge involves the amalgam of content knowledge and pedagogy. This is the professional knowledge teachers use to teach and manage mathematics classes.

The categories of teachers are: 1) novices (teachers with CCK); 2) apprentices (teachers with CCK and SCK); and 3) masters (teachers with CCK, SCK, and PCK).The three categories were called credentialed teachers (capable). The other category (teachers with insufficient CCK) represents those teachers who do not have the minimum required CCK who graduated with non-STEM teaching college degrees.

Fig. 2.2: Stage Two Stock-Flow Diagram
A stock-flow diagram developed during and after the second meeting. After discussion with the Center's leadership we decided to break down the pool of capable teachers into three categories (Novices, Apprentices and Masters) depending on the type of knowledge they have. Some links were omitted for simplicity (See Appendix D for the full model).



We assumed that the majority of teachers who graduated with STEM teaching degree become novices or apprentices but not masters because it requires teaching experience to become a master. The Center's mission is helping teachers acquire the required knowledge to become masters. Moreover, the possibility that teachers graduating with a non-STEM teaching degree and becoming STEM teachers was discussed and included in the model. However, these teachers do not have the minimum CCK to be considered STEM capable teachers. Again, the Center can help them to improve their STEM teaching skills through career professional programs. The gap between the total number of STEM teachers and the required number of STEM teachers will affect the flow of non-STEM teachers to become STEM teachers. The Center also works with experienced teachers (masters) to develop better curriculum. At this stage we assumed that even credentialed STEM teachers can leave if they are not satisfied with the teaching environment.

2.1.3 Stage Three: Discussing and Refining the Model and Discussing

During this third meeting the stock-flow diagram was again reviewed and modified, based on input from the STEM Center leadership team. Although the Center's focus is on improving STEM teacher quality, some members of the leadership pointed out that they are interested in tracking K-12 student's interest in STEM along with the level of proficiency. This led to disaggregating K-12 students into four categories; STEM proficient and interested, STEM proficient and not interested, STEM not proficient and interested, and STEM not proficient and not interested (see Fig. 2.3 a). However, the students' interest in STEM can also be monitored by tracking the number of students who opted to major in STEM. Furthermore, we modeled the assumption that college graduates with non-STEM teaching majors can become STEM teachers (See Fig. 2.3 b).

Fig. 2.3a: Stage Three Stock-Flow Diagram (first part)
This diagram is the result of breaking down K-12 students into four categories; STEM proficient and interested, STEM proficient and not interested, STEM non-proficient and not interested, and STEM non-proficient and not interested. Some links were omitted for simplicity (See Appendix D for the full model).

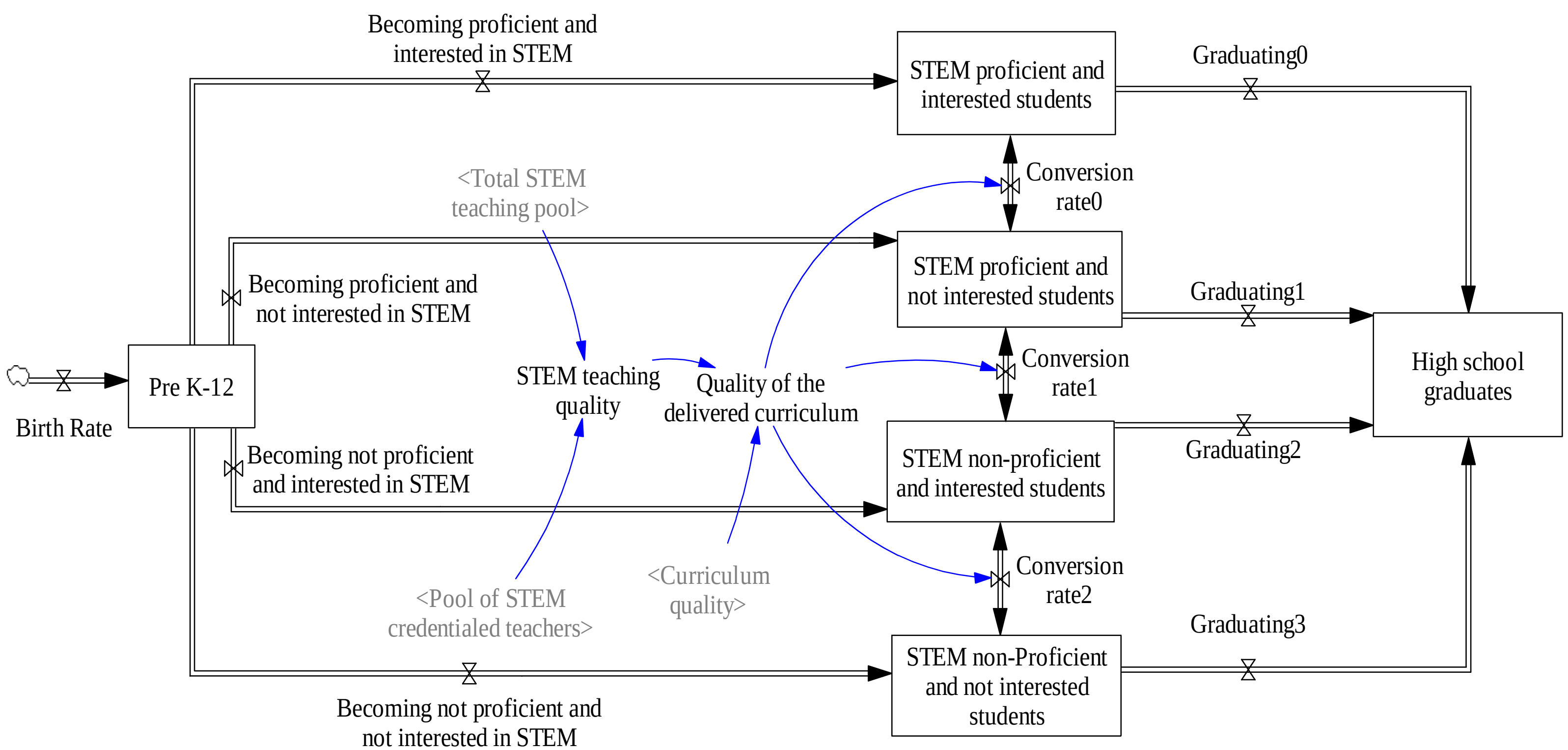
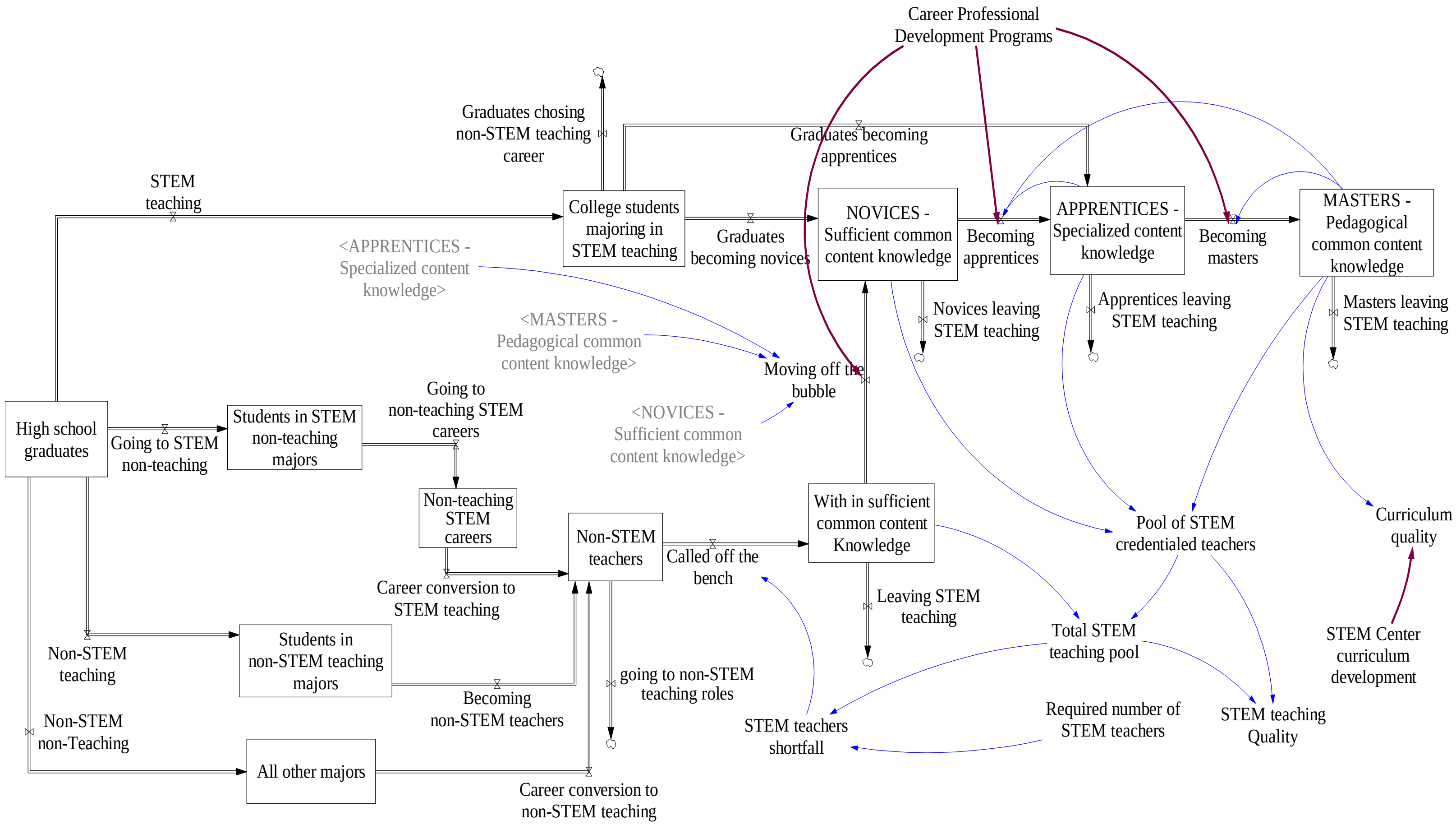


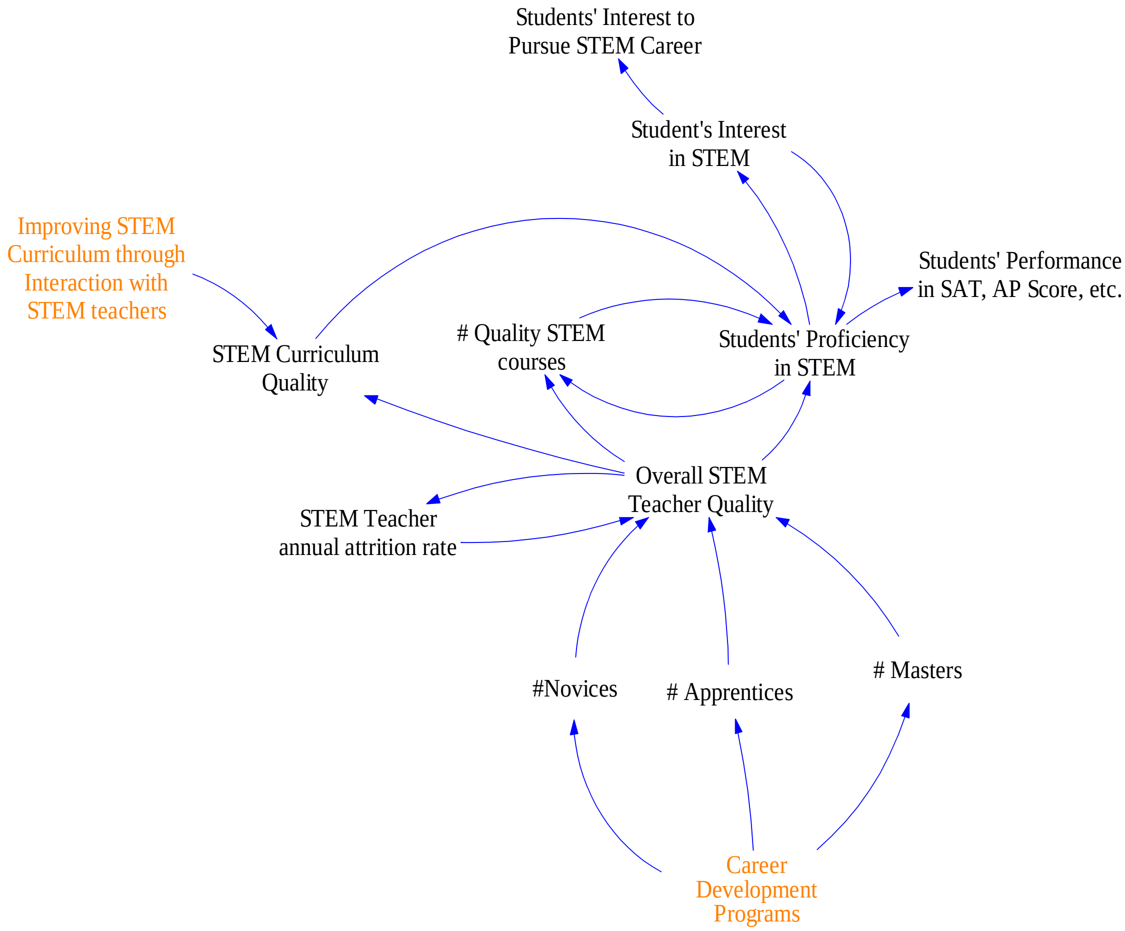
Fig. 2.3b: Stage Three Stock-flow diagram (second part)

A stock-flow diagram representing STEM teaching and how students from different majors can become STEM teachers. We assumed that those teachers with STEM teaching degree have the required CCK to become STEM teachers while teachers with other majors do not have sufficient CCK. Some links were omitted for simplicity (See Appendix D for the full model).



This stage also focused on building the BSC Strategy Map. The Strategy Map included all the strategic actions, measures, and actions and the causal relationships between them. The map was a simplified causal loop diagram which was distilled from the stock-flow diagram developed throughout the meetings (see Fig. 2.4).The simplicity of the map will allow the Center's leadership to focus their efforts on the variables and measures they believe are strategic to the Center's mission. The Strategy Map also helps members of the Center's leadership to have a unified vision that can be communicated to other stakeholders (Kaplan & Norton, 2004).

Fig 2.4: Stage Three Strategy Map
This diagram shows the Strategy Map that included all the goals, measures, and actions the Center's leadership mentioned during the process. The map was built after identifying the cause and effect relationships in the stock-flow diagram.



2.1.4 Stage Four: Discussing the Final Versions of the Strategy Map and Stock-Flow Diagram

During this stage the stock-flow model was discussed and minor changes were made to the model. The members of the Center's leadership noted that graduates with STEM (non-teaching) degrees posses the requisite common content knowledge (CCK) so when they choose to convert to STEM teaching they are considered novices. The other change was renaming the masters category to journeymen and adding a fourth category of teachers named masters. We assumed that masters are those teachers who have all the required knowledge and they are experienced. The Center's leadership suggested that the gap between the number of available STEM teachers and the required number can affect career conversion from STEM-non-teaching to STEM teaching careers (See Fig. 2.5)

Important feedback loops were discovered during the process which showed that the number of teachers in the different categories can be impacted by the number of teachers that have better STEM teaching skills. The assumption was that masters, for example, help teachers with insufficient common content knowledge, novices, apprentices, and journeymen to improve their teaching skills through mentoring and experience sharing (See Fig. 2.6).

Fig 2.5: Stage Four Stock-Flow Diagram

This diagram shows the final changes discussed at the fourth meeting. A new category of teachers (journeymen) was added and we also made the assumption that those teachers with STEM non-teaching degrees have the required CCK when they choose to become STEM teachers. Some links were omitted for simplicity (See Appendix D for the full model).

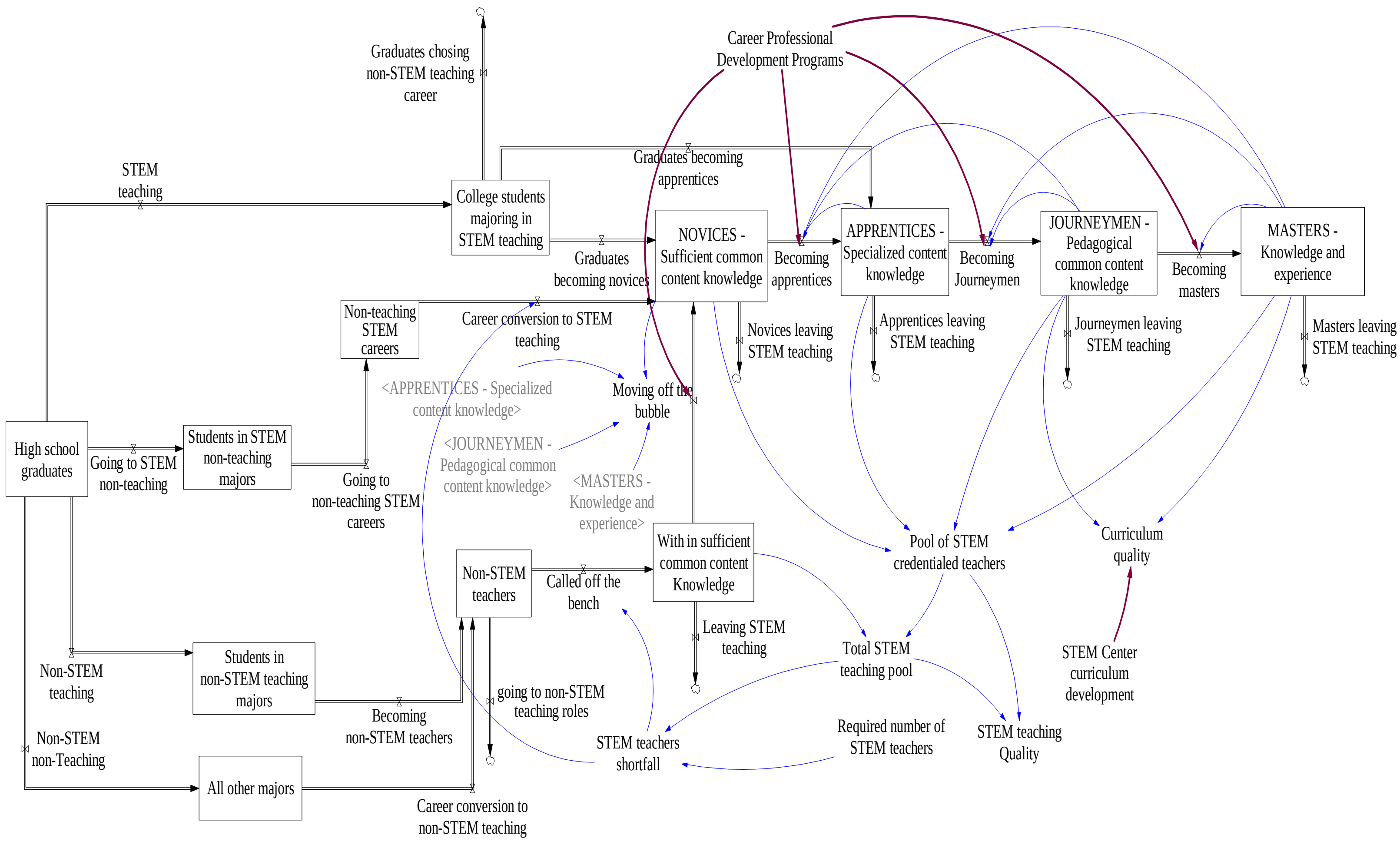
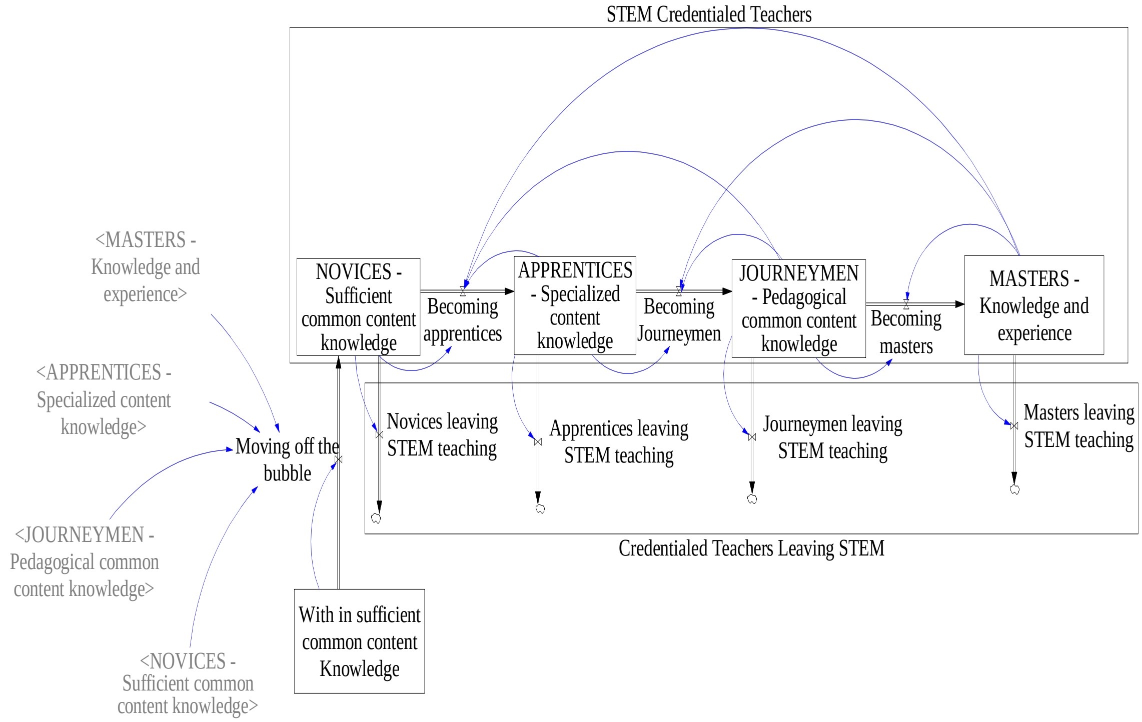


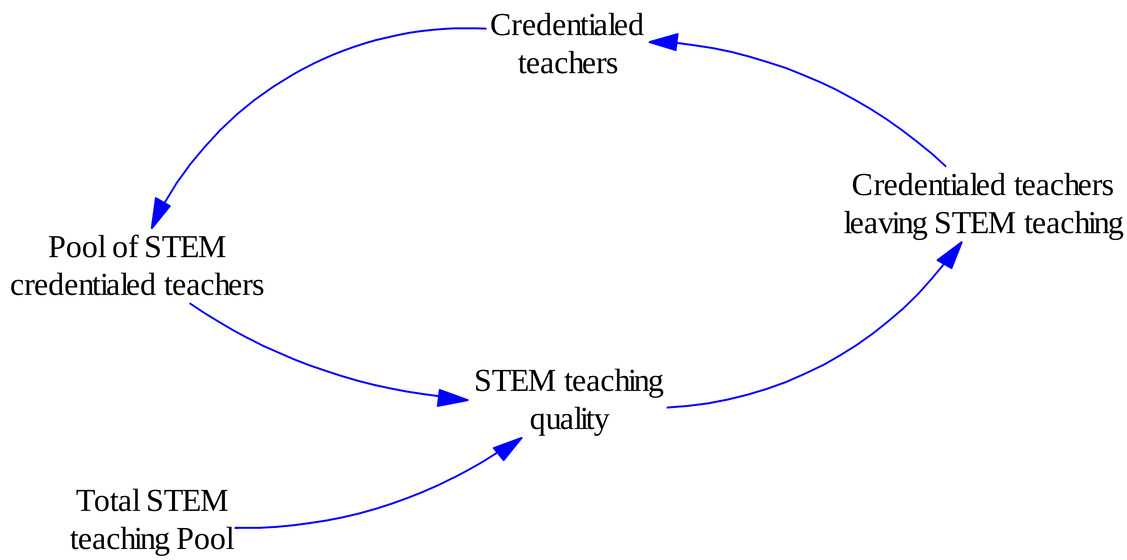
Fig 2.6: Feedbacks A
This diagram shows one of the important feedback loops that were discovered during the process. Masters, fore example, can help other teachers to improve their teaching skills. This will increase the pool of STEM credentialed teachers which will increase STEM teaching quality.



Moreover, if the Center was able to improve teachers' skills, those efforts will have an amplifying effect on teaching quality. The improved teaching quality will also increase job satisfaction, thereby reducing the number of credentialed teachers leaving STEM teaching. We assumed teaching quality can be measured as the ratio of the number of credentialed STEM teachers to the total number of STEM teachers (See Fig. 2.7). In this figure, and for simplicity, a causal loop diagram will be used to show the links between the variables.

Fig 2.7: Feedbacks B

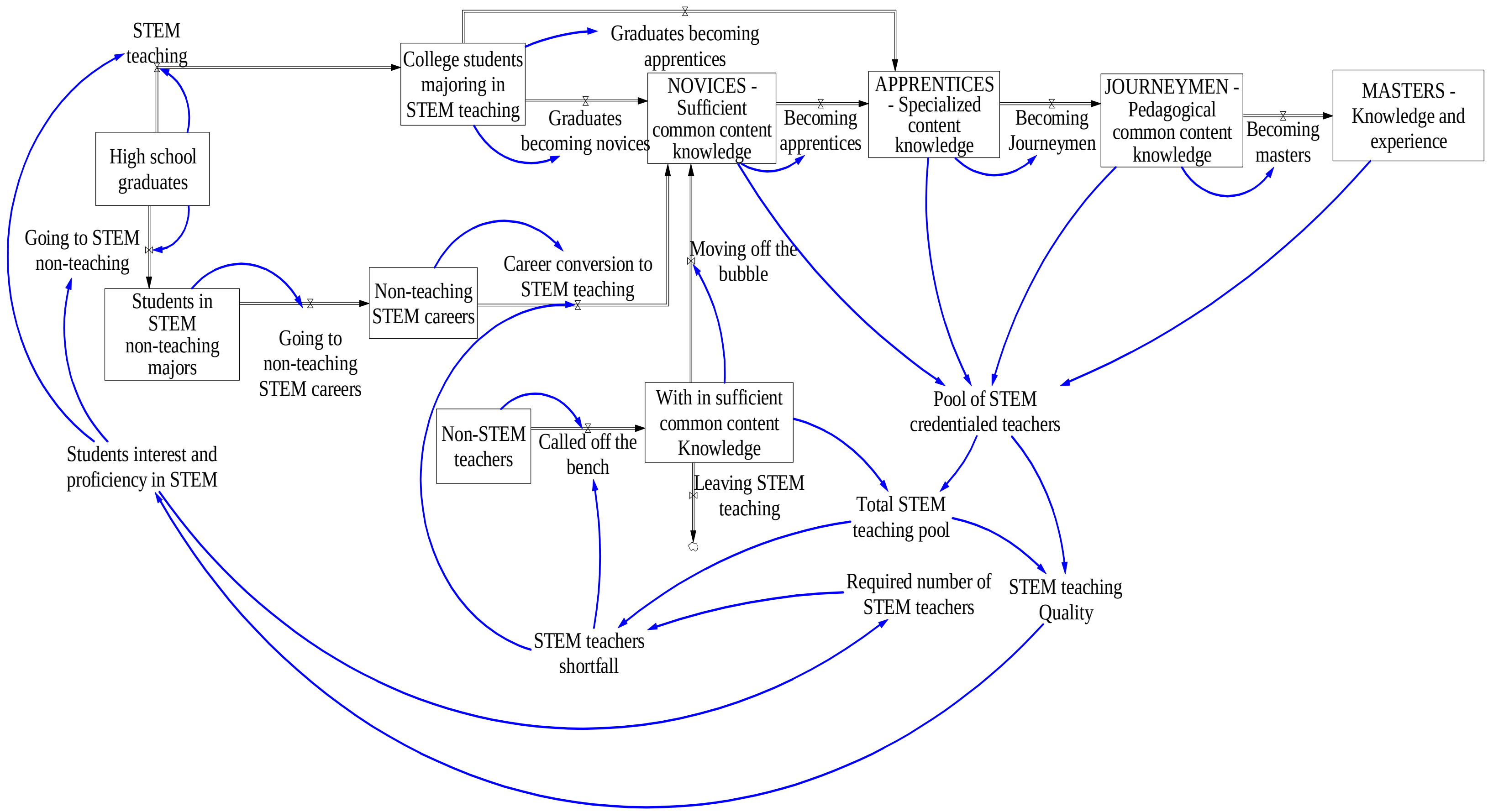
This diagram shows that how teaching quality impacts the of teachers leaving STEM teaching and how this affects the pool of credentialed STEM teachers



Other important feedback loops that were identified showed the effect of teaching quality on K-12 students' interest and proficiency in STEM and how that might lead to more students declaring STEM majors and also more required STEM teachers (See Fig. 2.7). If the Center was able to improve teaching quality be helping teachers to improve their STEM teaching skills, that will increase K-12 students' interest and proficiency in STEM. This will lead to more students pursuing degrees in STEM teaching or STEM non-teaching which will increase the number of teachers that have the sufficient CCK to be considered credentialed STEM teachers. The pool of STEM credentialed teachers will increase which means better teaching quality.

Fig 2.8: Feedbacks C

This diagram shows how teaching quality can impact students' interest and proficiency in STEM which will impact the number of college students with STEM majors. The number of college students with STEM majors will affect the flow of credentialed STEM teachers which an important component of STEM teaching quality. Moreover, students' interest and proficiency in STEM impacts the required number of STEM teachers which can affect the gap between the available and required STEM teachers. This gap has an effect on the rate at which non-STEM teachers become STEM teachers and the rate of people with STEM nonteaching degree converting to STEM teaching. Both of these rates will impact teaching quality.

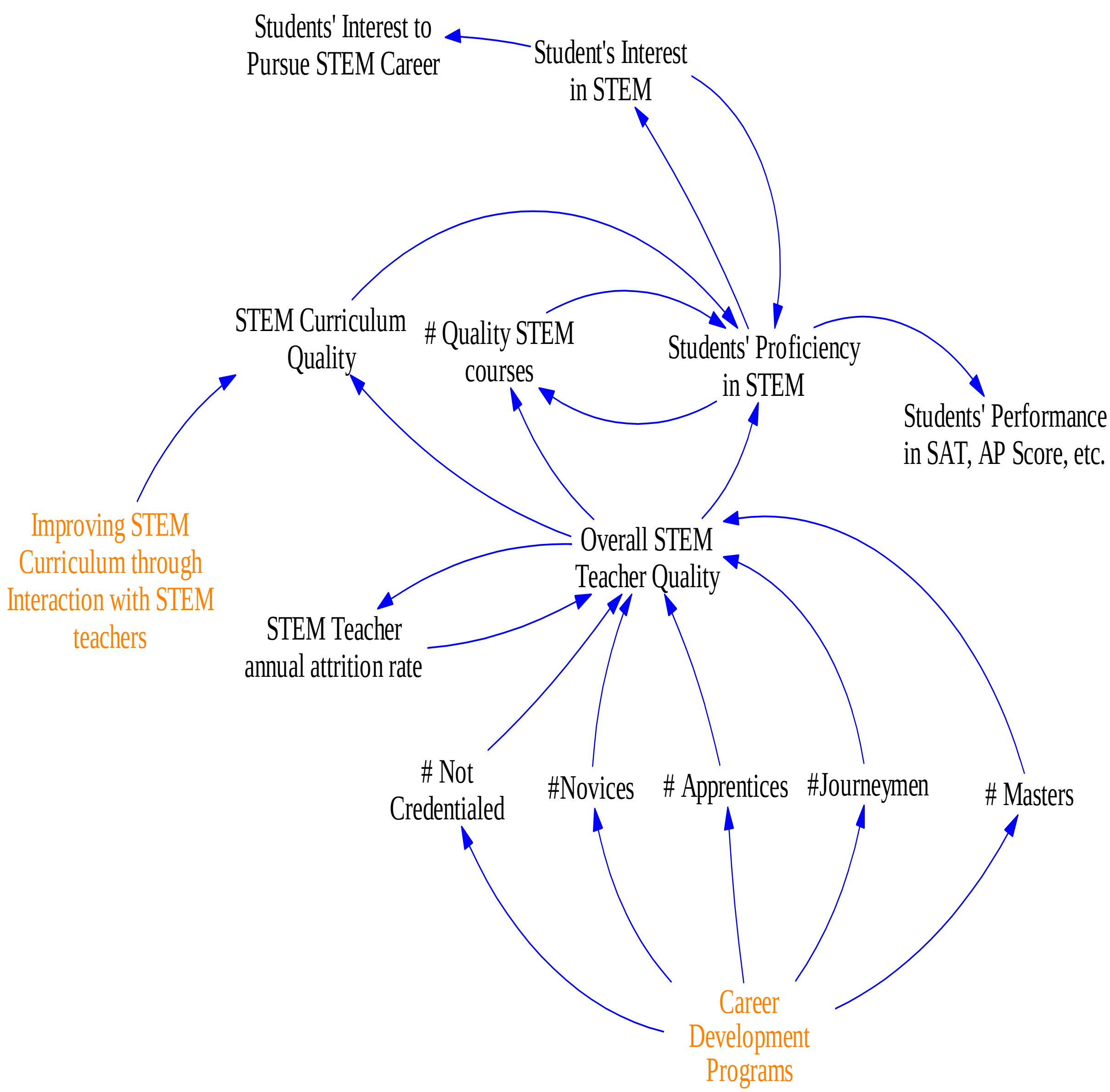


Moreover, we assumed that if students are more interested and proficient in STEM, they will start taking more STEM courses which increases the required number of STEM teachers. The gap between the total number of STEM teachers and the required number will broaden making a fraction of those who are non-STEM teachers want to become STEM teachers. This will decrease teaching quality because it will increase the number of teachers with insufficient CCK (we assumed that non-STEM teachers do not have sufficient CCK). The gap will also affect the career conversion rate of those who have non-teaching STEM degree and opted to become STEM teachers. This will increase the pool of credentialed STEM teachers which will increase teaching quality.

Some changes were made on the Strategy Map to reflect the changes that we made to the stock-flow model (See Fig. 2.8). Recommendations were made regarding focusing the efforts and actions to improve the strategic measures and achieve the goals stated by the Center. Among the other recommendation were focusing on pursuing methods to measure the factors and indictors that are strategic to the Center's mission and making sure that the goals reflect the Center's mission. At the end of the last meeting the Center's leadership was asked to answer a questionnaire. The questions focused on the level of insight the Center's leadership gained from the process and how this process helped them identify their goals, strategic indicator or measures and the required actions to achieve these goals. They were also asked to define each measure in the Strategy Map because the definition will help them define methods for measurement.

Fig 2.8: Stage Four Strategy Map

The Final Strategy Map that arose from making the final changes on the stock-flow diagram



Chapter Three

3.1 Results and Discussion

The leadership of the Center for STEM Education and Outreach at James Madison was asked to answer a number of questions that focused on what value and insight was gained from using system dynamics and the Balanced Scorecard as strategic planning tools. The questions were sent to each member and the answers to the questions informed the results of this research. The following sections begin with each question in bold, followed by a summary of the feedback from the Center's leadership team.

Did this process help you identify your goals? How?

Three members (Dr. Benson, Dr. Kolvoord, and Dr. Lovin) agreed that this process gave them the opportunity to discuss the Center's main focus and direction. They explained that the discussion made these goals clearer and more explicit. Dr. Kolvoord wrote: "It was very interesting to have the four-way conversation to try to develop a common understanding (and vision) of the aims of the Center." Dr. Lovin noted that "the value" of the process was enabling the Center's leadership to become more explicit about the "goals, required actions, and strategies" in a way that enabled them to have a "clearer picture" of the direction of the Center. While Dr. Benson's answer was: "The process helps you be more systematic and explicit." Dr. Pyle's response, however, was different. He said he does not think that the Center's goals became clearer to him but it is easier now to "define the work of the Center to outside audiences"

What insight did you gain regarding the required actions and strategies to achieve your goals?

Dr. Kolvoord and Dr. Lovin answered that the process did not introduce new actions and that they were not surprised with the actions that were discussed throughout the process. However, they pointed out that the process highlighted the interrelationships between the goals and actions and showed how the actions are now explicitly aligned with the Center's ultimate goals. Moreover, Dr. Benson noted that this process offered a "Clearer picture of where we could strategically intervene and the resultant impact on the greater system." Dr. Pyle said that the process came up with a refined definition of the Center and now they have "clearer actions of the Center for the future."

How did the process make you focus on strategic measures?

The answers showed that the process was an effective approach to discover measures that are strategic to the Center's mission. Dr. Kolvoord wrote: "The process forced me to think about specific quantitative measures." He explained that usually during their discussions they spend the time talking about K-12 STEM education (the system they are trying to improve) in "very abstract terms" ignoring methods to monitor changes in that system. Dr. Benson and Dr. Lovin said that by being explicit about the variables and goals, they became more able to determine what strategic measures they needed to identify. Dr. Lovin added: "It also became apparent that while we may not have a way to measure something, we still need to include it in the mapping because it's something we need to find a way to track. If it's not included, then it tends to be forgotten or ignored." Dr. Pyle agreed that the process will make them focus "for establishing future priorities."

Did this process improve or refine your understanding of the STEM education system by understanding the causal relationships between the variables of the system? Please explain

Three (Dr. Benson, Dr. Lovin, and Dr. Pyle) wrote that they were not surprised about the causal relationships between the factors and variables of K-12 STEM education system. Dr. Kolvoord's answer was different; he wrote "The process was very useful in focusing the conversation on specific causal relationships in the system." He explained that the Center's leadership has "spent too little time on thinking about the connections and trying to understand where our points of highest impact are." He mentioned that the process enabled them to "separate the key parts of the system (cf. the different classes of teachers) into its component parts." However, they all agreed that process made them articulate and represent the causal relationships explicitly.

Do you think that having a few strategic indicators represented by the Strategy Map developed throughout the process will make it easier to manage the Center's actions?

Everybody agreed that this was useful because it broke down the system into more manageable pieces. Dr. Benson was brief and simple and his answer was "Definitely." Dr. Kolvoord's answer was: "I think a Strategy Map will actually be very useful to help us focus on monitoring our progress and be continuing to work to develop ways to measure the different parts of the system. This has been a very useful exercise." Dr. Lovin said: "The level of detail with which we could break something down makes it appear to be a little more manageable because we have specific actions and strategies on which we can focus our efforts." Dr. Pyle explained that the Strategy Map will enable them to prioritize their work and he added that their "approach to explaining the work of the center to external audiences, such as funding agencies, is enhanced."

3.2 Alignment with the SRMN Model

The SRMN model was built to help policy makers decide what actions and strategies required to promote STEM education and increase the number of college graduates with STEM degrees. The model represented the national U.S. education system showing the journey of a student from birth to retirement. A number of actions were suggested and tested in that model and the results showed that improving STEM teacher's quality is fundamental to increase K-12 student's interest and proficiency in STEM. The results, however, did not explain what type of skills or knowledge teachers need to develop or improve.

The leadership of the Center for STEM Education and Outreach at James Madison University also believes that improving K-12 STEM teaching and curriculum quality is important to promote STEM education in the State of Virginia. During our four meetings, they stated that improving teachers quality be accomplished through professional development programs and interaction with K-12 teachers. Moreover, we were able to identify specific types of knowledge (CCK, SCK, and PDK) that need to be developed to improve STEM teaching quality. This was included in the model developed throughout this process. We calcified STEM teachers into five categories: 1) Teachers with insufficient CCK; 2) Novices; 3) Apprentices; 4) Journeymen; and 5) Masters. We said that teachers with insufficient CCK are those who are STEM teachers with non-STEM college degrees. Novices, apprentices, journeymen and masters are teachers with STEM college degree with different level of knowledge and experience. Novices are teachers with CCK; apprentices are teachers with CCK and SCK; journeymen are teachers with CCK, SCK, and PCK. Masters are experienced teachers with CCK, SCK, and PCK. Each category of teachers has certain level of knowledge. We were also able to highlight the effect of how increasing the number of credentialed STEM teachers can affect teaching quality which affects attrition or turnover rate amongst STEM teachers.

In the SRMN model teachers were categorized as STEM capable teachers and STEM non-capable teachers without any distinction between the two types of teachers. Again, the model did not show what knowledge non-capable teachers need to develop or improve to become capable teachers. Moreover, the model did not show the effect of how capable teachers help non-capable teachers improve their teaching quality. In addition, the SRMN model did not show the effect of teaching quality on attrition or turnover rate. I believe that the findings of this study will be a valuable addition to the SRMN efforts and if these findings were integrated with the SRMN model, better results will be obtained.

It is also worth mentioning that the SRMN model was used as a strategy testing tool (i.e. to find the best strategies for achieving goals). That means that the SRMN model was used to evaluate different actions and strategies. In this study, we did not try to test or evaluate different actions and strategies. We assumed that the actions stated by the

Center's leadership are the required actions to achieve the Center's goals (though one of the goals was to see how well the actions were aligned with the Center's goals, given the causal structure in the system). In other words the SRMN model was used a strategy formulation tool while the model developed in this study was used a strategy implementation tool.

Chapter Four

4.1 Conclusion

The case study described in this thesis has demonstrated some benefits obtained by the STEM Education Outreach Center at James Madison University in using system dynamics and the BSC to enhance strategy design and planning. This thesis investigated the use of strategic planning tools to help the Center to define their goals, actions, and strategic measures. The four-stage methodology used in this thesis helped the Center's leadership to explicitly understand the causal relationships between the variables in system they are trying to impact with their actions.

Four meetings were conducted with the Center's leadership and a qualitative system dynamics model and a BSC Strategy Map were developed during these meetings. Questions were sent to each member of the Center's leadership that focused on the insight and benefits obtained from the whole process. The answers showed that the process gave the Center's leadership the opportunity to discuss the Center's main focus and direction. While the process did not offer new actions and strategies, the Center's leadership said that the process helped them to articulate the alignment between the Center's actions and its mission. The system dynamics model developed in this process helped the leadership to discuss their assumptions and make them explicit. The Strategy Map made them focus on a few strategic measures showing the cause-effect relationships between these measures. This makes the Strategy Map an effective method to communicate the Center's direction to outside audiences.

There are differences between this study and the SRMN model. However, alignment between the two works was identified. The results of the SRMN model suggest that STEM teachers' quality is very important for improving K-12 students' interest and proficiency in STEM. However, the results do not specify the types of knowledge STEM teachers need. Since STEM teachers' quality is the main focus, it was very important to identify the types of skills or knowledge teachers need to become qualified STEM teachers. In this study we were able to identify the types of knowledge a qualified STEM teacher needs and included that in the new model.

4.2 Recommendations

In order to obtain better results, the Center leadership must focus their efforts on the Strategy Map developed in this thesis. They must pursue methods to continually improve and refine this Strategy Map and examine if there are other measures or performance indicators need to be added or removed. Moreover, measures or factors should be included in the Strategy Map as long as they are strategic even if there are no methods to measure them. Yet, measurement methods must be pursued. In addition, it is very important that the Center's leadership be very clear about the Center's goals and frequently test whether the stated goals are aligned with the Center's main mission. Since it includes all the strategic measures along with the causal link between these measures, BSC Strategy Map is an excellent communication method the Center must use to communicate to outside audiences.

Although this study helped in making the connections between the Center's goals and actions explicit, a quantified model, however, would enable the Center's leadership to asses and test actions and anticipate different scenarios. The Center's leadership would have the ability to test their mental models and their understanding of the causal relationships that link all the factors in the system. Building a quantified model will enable the leadership to refine the Strategy Map developed in this study. By quantifying the model I mean quantifying the causal relationships shown in the qualitative model. This involves collecting qualitative and quantitative data about these relationships. The goal is finding the mathematical expressions for these relations.

As mentioned above, one of the benefits of building a quantified model is testing different actions and strategies. In other words, from observing the effect of each action the Center can identify the most effective actions for achieving the Center's goals. The model can also be used to refine the Strategy Map by observing how each of the critical measures can affect the Center's goals. For example if students' performance in SAT improved while students' interest in STEM did not change that means students' performance in SAT is not strategic and should be eliminated from the Strategy Map. A measure is considered strategic only if its value gives an indication of the whole system performance. In sum, strategic planning is a dynamic process that requires a continual refining and adjustment.

Appendix A:

Questions sent to the Center’s leadership

1. Did the process help you identify your goals? How?
2. What insight did you gain regarding the required actions and strategies to achieve your goals?
3. How did the process make you focus on strategic measures
4. Did this process improve or refine your understanding of the STEM education system by understanding the causal relationships between the variables of the system? Please explain
5. Do you think that having a few strategic indicators represented by the Strategy Map developed throughout the process will make it easier to manage the Center’s actions?

Appendix B:

Meetings Conducted throughout the Process

1. First meeting – Friday, February 26th 2010, 4:00 - 5:00 p.m.

   Attendees: Dr. Arthur Benson, Dr. Robert Kolvoord, Dr. Lou Ann Lovin, and Dr. Eric Pyle

2. Second meeting – Monday March 15th 2010, 8:00 – 9:30 a.m.

   Attendees: Dr. Arthur Benson, Dr. Michael Deaton, Dr. Kolvoord, and Dr. Lou Ann Lovin

3. Third Meeting – Friday March 19th 2010, 9:00-10:30 a.m.

   Attendees: Dr. Michael Deaton, Dr. Lou Ann Lovin, and Dr. Eric Pyle

4. Fourth meeting: Monday March 29th 2010, 8:15-9:00 a.m.

   Attendees: Dr. Arthur Benson, Dr. Robert Kolvoord, Dr. Lou Ann Lovin, and Dr. Eric Pyle

Appendix C:

Definitions for the Model's Variables

Table C.1: Variables Definitions

Variable	Definition	Unit
Pre K-12	#kids before going to K-12	Kids
Becoming proficient and interested in STEM	Rate of kids developing proficiency and interest in STEM before going to K-12	Kids/year
Becoming proficient and not interest in STEM	Rate of kids developing proficiency but not interest in STEM before going to K-12	Kids/year
Becoming not proficient and interested in STEM	Rate of kids developing interest but not proficiency in STEM before going to K-12	Kids/year
Becoming not proficient and not interest in STEM	Rate of kids who are not developing interest or proficiency in STEM before going to K-12	Kids/year
STEM proficient and interested students	K-12 students who developed proficiency and interest in STEM	K-12 Students
STEM proficient and not interested students	K-12 students who developed proficiency but they are not interested in STEM	K- 12 Students
STEM non-proficient and interested students	K-12 students who did not develop proficiency but they are interested in STEM	K-12 Students
STEM non-proficient and not interested students	K-12 students who did not develop proficiency or interest in STEM	K-12 Students
Conversion rate	The rate at which K-12 students convert from one of the four categories to another depending on their proficiency and interest in STEM	K-12 Students/year
Graduating	The rate at which students graduate from high school	K-12 Students/year
High school graduates	#high school graduates	High school graduates
STEM teaching	Rate of college students	College students/

	majoring in STEM teaching	year
STEM non-teaching	Rate of college students majoring in STEM non-teaching majors	College students/ year
Non-STEM teaching	Rate of college students majoring in non-STEM teaching majors	College students/ year
Non-STEM non-teaching	Rate of college students majoring in non-STEM, non-teaching majors	College students/ year
College Students majoring in STEM teaching	#College students studying STEM teaching	College students
Students in STEM non-teaching majors	#College students studying STEM non-teaching	College Students
Students in non-STEM teaching majors	#College students studying non-STEM teaching	College Students
All other majors	#College students studying any other field	College Students
Going to STEM non-teaching careers	Rate of STEM non-teaching graduates going to STEM non-teaching careers	Graduates/ year
Becoming non-STEM teachers	Rate of non-STEM teaching graduates going to non-STEM teaching careers	Graduates/ year
Called of the bench		
Career conversion to STEM teaching	Rate of STEM non-teaching professionals going to STEM teaching careers	professionals/year
Career conversion non-STEM teaching	Rate of graduates from all other majors going to non-STEM teaching	Graduates/ year
Non-teaching STEM careers	#Graduates with STEM non-teaching degrees chose non-teaching STEM career	non-teaching STEM professionals
Non-STEM teachers	#non-STEM teachers	Teachers
Graduates becoming novices	#Graduates with STEM teaching degree becoming novices	Graduates/year
Graduates becoming apprentices	#Graduates with STEM teaching degree becoming apprentices	Graduates/year
Novices	#STEM teachers with CCK	Teachers
Becoming apprentices	Rate of Novices becoming apprentices after improving their SCK	Teachers/year

Apprentices	#STEM teachers with CCK and SCK	Teachers
Becoming journeymen	Rate of Apprentices becoming journeymen after improving their PCK	Teachers/year
Journeymen	#STEM teachers with CCK, SCK, and PCK	Teachers
Becoming Masters	Rate of apprentices becoming masters after becoming experienced	Teachers/year
Maters	#STEM teachers with CCK, SCK, PCK, and experience	Teachers
With insufficient CCK	#STEM teachers with who do not have the minimum CCK	teachers
Moving off the bubble	Rate of teachers with insufficient CCK becoming novices after improving their CCK	Teachers/year
Novices leaving STEM teaching	Novices turnover rate	Teachers/year
Apprentices leaving STEM teaching	Apprentices turnover rate	Teachers/year
Journeymen leaving STEM teaching	Journeymen turnover rate	Teachers/year
Masters leaving STEM Teaching	Masters turnover rate	Teachers/year
Pool of STEM credentialed teachers	Total number of novices, apprentices, journeymen and master.	Teachers
Total STEM teaching pool	Total number of pool of STEM credentialed teachers and teachers with insufficient CCK	Teachers
STEM teaching quality	Teaching quality indication which can be measured as the ratio of Pool of STEM credentialed teachers to the Total STEM teaching pool	
STEM curriculum quality	The quality of K-12 STEM courses and materials	
Quality of the delivered curriculum	The actual quality of the curriculum taught to K-12 students. It depends on teaching quality and curriculum quality	
Required number of STEM teachers	#number of teachers required to meet K-12 STEM teaching demand	Teachers

STEM teachers shortfall	The gap between the required number of STEM teachers and total STEM teaching pool	Teachers
STEM center curriculum development	The Center’s efforts to improve K-12 STEM curriculum	Time and/or $
Career professional development programs	The Center’s efforts to improve STEM teaching quality through interacting with K-12 STEM teachers	Time and/or $

Appendix D:

Complete Stock-Flow Model

Fig D.1: Final Model A

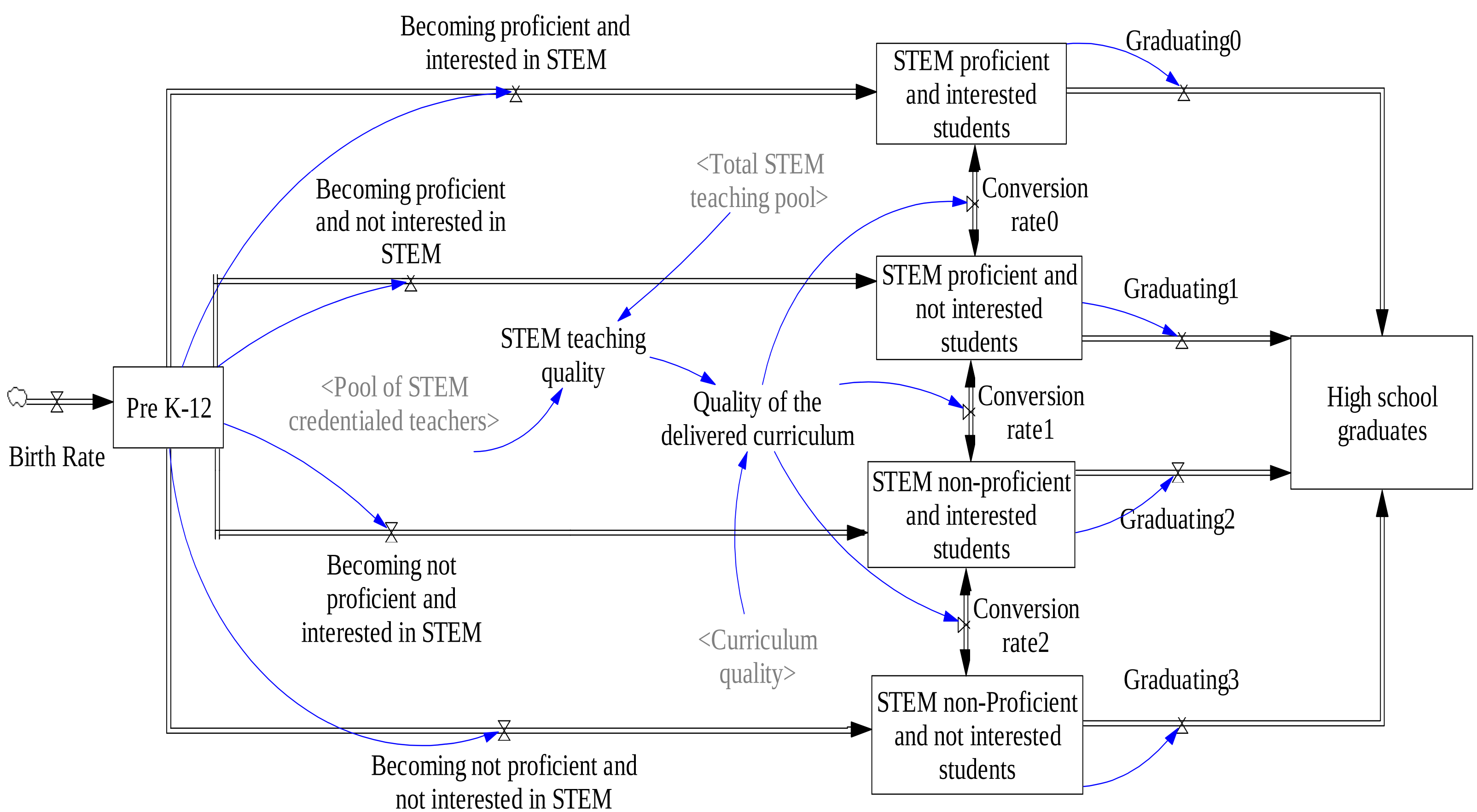
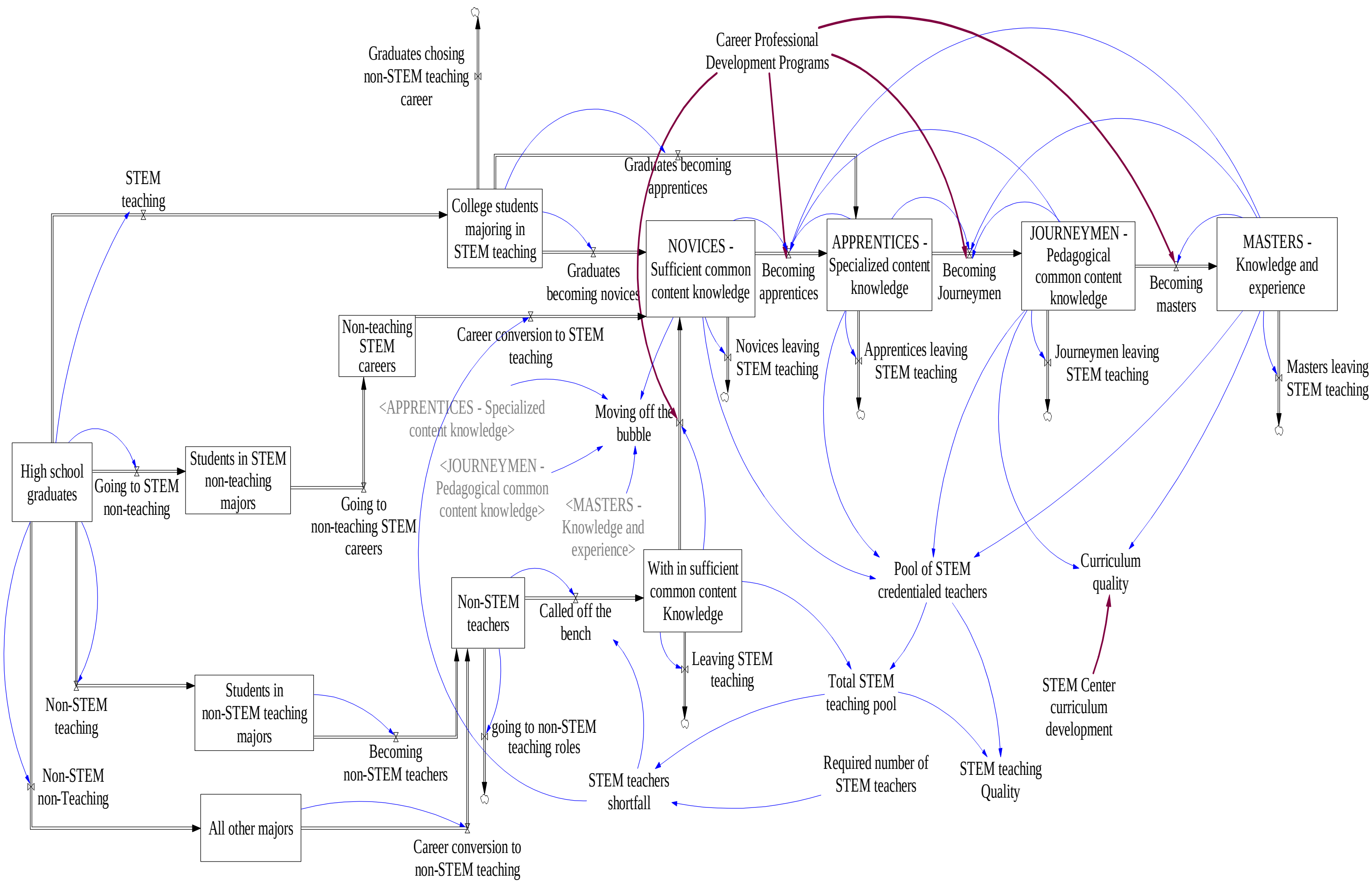


Fig D.2: Final Model B



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