Policy Innovations to Enhance the STEM Talent Pipeline

WRT-1042 & WRT-1068

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ANNUAL RESEARCH REVIEW 2022

SYSTEMS ENGINEERING RESEARCH CENTER

- Multi-Faceted Research Plan
- Fundamental Questions
- Broader Perspective
- Definitions of STEM
- STEM Talent Pipeline Model
- Stakeholder Decision Making
- Student Recruitment & Retention
- STW Education & Training
- Next Steps

Research Plan

- WRT-1042 (2021-2022)
    1. Development of an economic model of the higher education ecosystem to understand financial drivers of the overall university system and drivers within the research environment.
    2. Talent identification and recruitment to protect and promote the domestic and international STEM workforce
    3. Identification of selected universities to support their achieving preeminence in strategic areas
- WRT-1068 (2022-2023)
    4. Engaging and nurturing promising high school students towards STEM, and perhaps national security application domains
    5. Modeling policy Instruments to better understand short and long term impacts, both positive and negative on the US STEM Talent Pipeline

Fundamental Questions

- What percentage of K-12 students graduate “STEM–ready”?
- What percentage of these students choose STEM college majors?
- What percentage of STEM college majors graduate with STEM degrees?
- What percentage of these graduates are employed in the Defense Industrial Base?
- How can these percentages be increased?
  - K-12 interventions to increase interest, commitment & success
  - Undergraduate interventions to increase retention & success
  - Career interventions to increase attraction & commitment to DIB
- Most difficult challenge is K-12

Broader Perspective

- STEM graduate workforce is critical to DIB design & development
- Skilled Technical Workforce (STW) is central to production, operation & maintenance
- Both are critical to the US economy

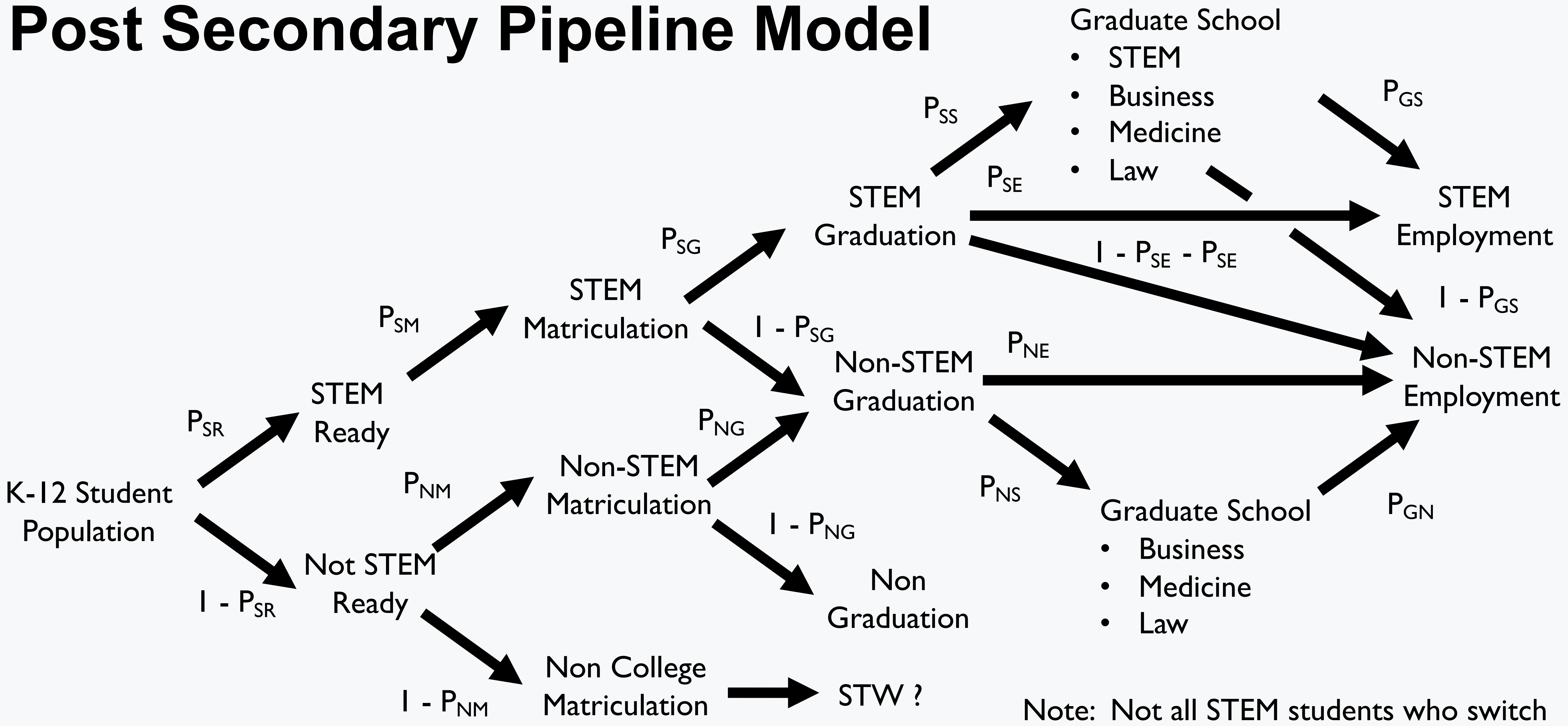
Definitions of STEM

- **STEM = science, technology, engineering, math**
  - Should science include social sciences?
  - Economics, engineering psychology & industrial/org. psychology might fit
- STEMM = science, technology, engineering, math, medicine
  - Most medical school students have STEM undergraduate degrees
  - Should undergraduate degrees in nursing be considered STEM?
- STEAM = science, technology, engineering, arts, math
  - Some arts are highly technology-based
  - Augmented reality & gaming are good examples

STEM Talent Pipeline Model

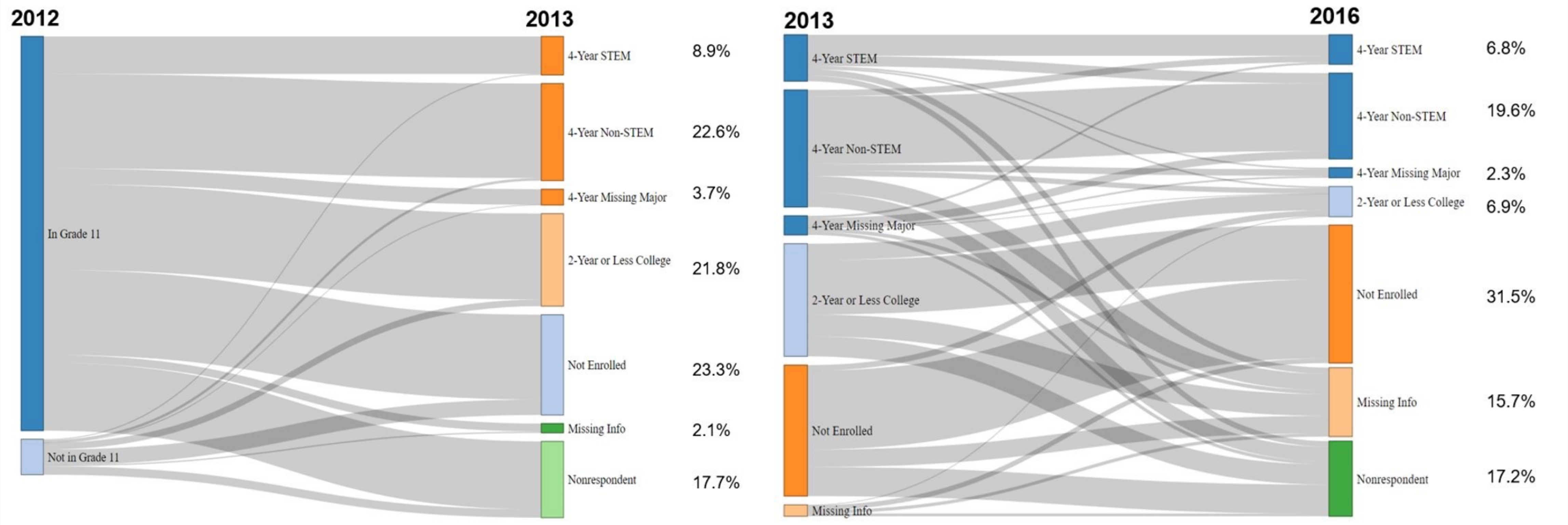
- Post Secondary Pipeline Model
- Elementary & Secondary Schools Model
- Parameters of Pipeline Model
- Rough Estimates from Literature
- Impacts of Policy Interventions

Post Secondary Pipeline Model



Note: Not all STEM students who switch to Non-STEM subsequently graduate

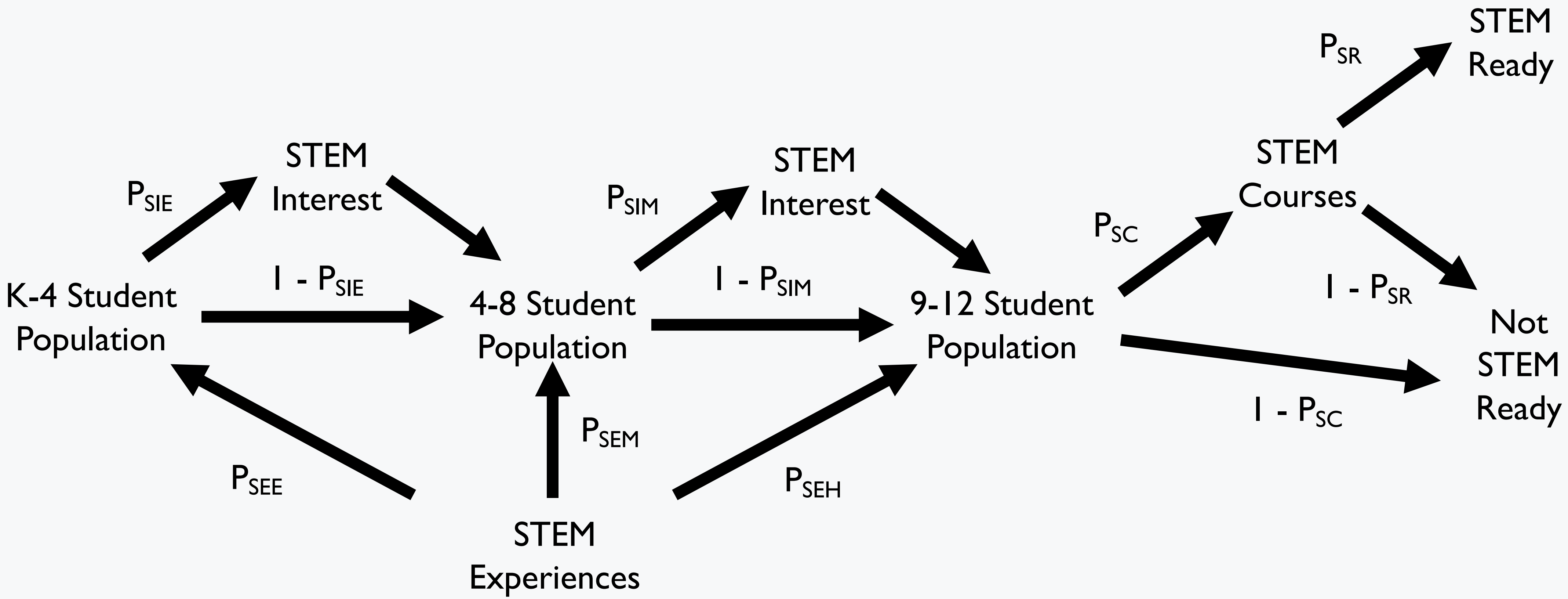
Sankey Diagrams of Post-Secondary Pipeline Flows



Data source: U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009

Left: 2012-13 data on where the student went after high school, and choice of major if chosen (if at a four-year institution)
Right: 2013-2016 data on the flow of students during their college years. This includes major change and no college enrollment. Nonrespondent data from 2012-2013 not included in this diagram.

K-12 Talent Pipeline



Parameters of Pipeline Model

	Elementary & Secondary Schools		Post-Secondary School
PSIE	Prob STEM interest in elementary school	PSM	Probability STEM matriculation
PSEE	Prob STEM experience in elementary school	PNM	Probability Non-STEM matriculation
PSIM	Prob STEM interest in middle school	PSG	Probability STEM graduation
PSEM	Prob STEM experience in middle school	PNG	Probability Non-STEM graduation
PSEH	Prob STEM experience in high school	PSS	Probability STEM to graduate school
PSC	Prob STEM courses in high school	PSE	Probability STEM to STEM employment
PSR	Prob STEM ready	PNS	Probability Non-STEM to graduate school
		PNE	Probability Non-STEM to employment
		PGS	Probability graduate school to STEM employment
		PGN	Probability graduate school to Non-STEM employment

Rough Estimates from Literature

- 16% of HS grads are STEM ready
- 20+% of HS grads choose STEM majors
- 50% of STEM students graduate non-STEM
- 60% of STEM grads take non-STEM jobs
- 90% of STEM grads use STEM skills in jobs
- Better evidence-based estimates being researched

Impacts of Policy Interventions

Policies	Impacts of Policies
Incentives to provide offerings that increase students' interest and competencies.	Increase PSIE, PSIM, PSC
Incentives to provide STEM experiences to increase interest and competencies.	Increase PSEE, PSIE, PSEM, PSIM, PSEH
Incentives for industry to provide paid internships	Increase PSEH, PSC, PSR
Information that enhances students' abilities to make well-informed decisions	Increase PSM
Incentives to provide accessible offerings at community colleges and universities.	Increase PSM, PSG
Incentives for vocationally oriented offerings.	Increase PSM, PSH, PSE
Incentives to provide knowledgeable and skilled counseling and coaching.	Increase PSG, PNG
Scholarships to foster knowledgeable, skilled, and motivated STEM professionals	Increase PSR, PSM, PSG, PSS, PSE
Incentives to encourage employee involvement in STEM professional societies	Increase PSE, PSS
Incentives to participate in regional alumni associations	Increase PSE, PSS
Information to support identifying and pursuing STEM employment opportunities.	Increase PSE,PSS

Stakeholder Decision Making

- Students
- Institutions
- Government -- TBD
- Incentive Mechanisms

How Students Make Decisions

Choice of Institution
- Brand Value
- Costs of Matriculation
- Location of Institution
- Stated vs. Derived Factors

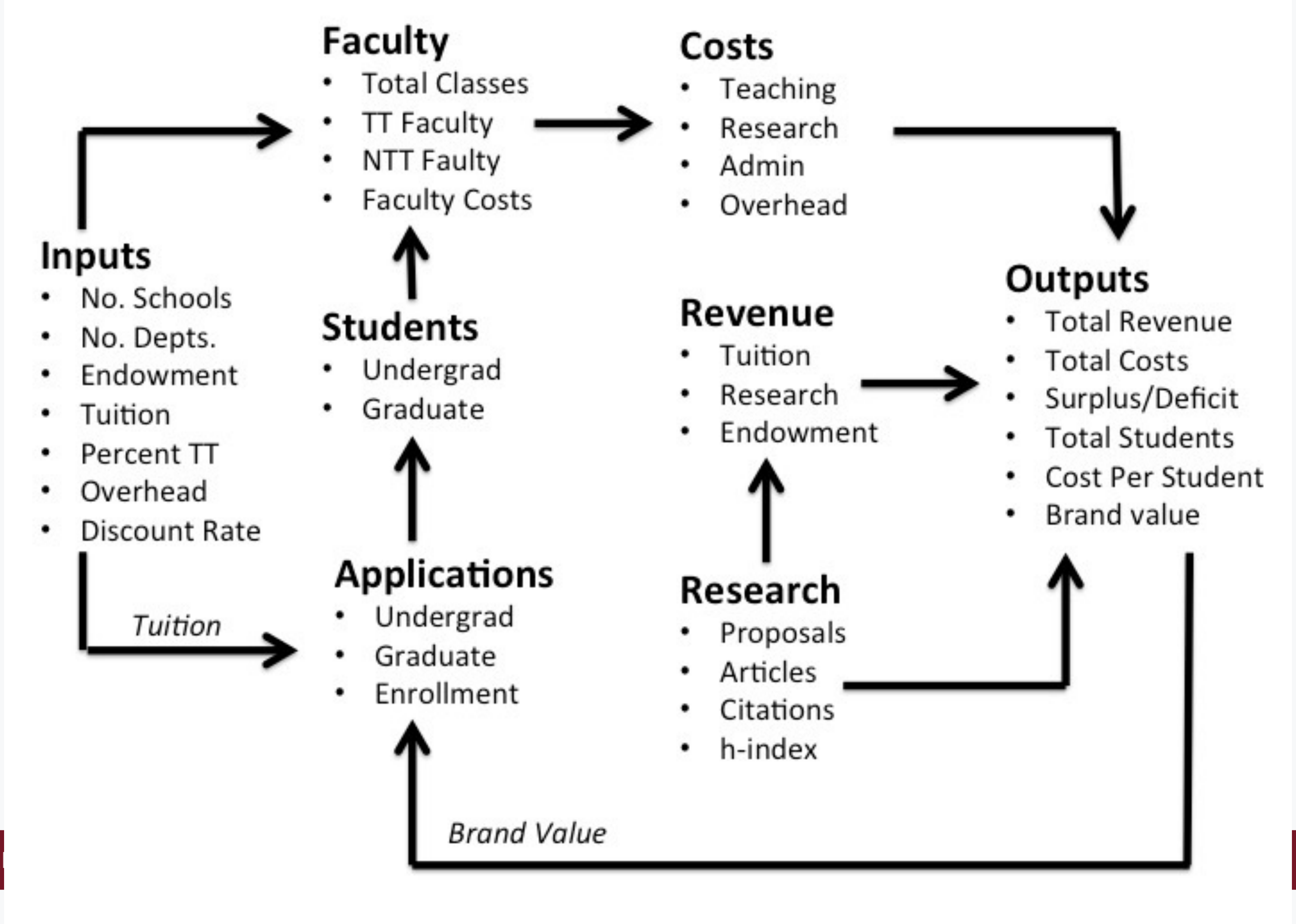
Choice of Major
- Interest in Subject
- Aptitude for Subject
- Career Potential
- Exposure to Subject
- Teachers' Advice
- HS Experiences
- Family Experiences

Choice of STEM Majors
- Exposure to STEM
- Math Self-Efficacy Beliefs
- Pre-College Engr. Exposure
- HS Experiences
- Financial Aid
- Career Potential
- Societal Impacts

Behavioral Factors
- Self-Control
- Willingness to Compete
- Intrinsic Motivation
- Self-Confidence
- Career Identities
- Long-Term Focus

Employment
- 36%: Jobs with Title Engineer
- 90%: Jobs Benefitting From Engineering Skills

How Universities Make Decisions



Incentive Structures

Incentive Type	Locus of Incentives		
	Student	Institution	Employment
Opportunity	Univ: Acceptance Co-Op: Selection ROTC: Selection SMART: Selection Univ: Desirable major Univ: Job Placement Univ: Academic/personal Support	Increased Enrollment/ Retention Increased Talent Quality Expanded Relationships, e.g. DoD, Corporate Sponsors	Interesting Projects Unstructured Time Time With Leaders
Recognition	Univ: Honors, Graduation Co-Op: Job Offer ROTC: Commission SMART: Graduation Univ: Campus Leadership, Special Projects	Increased Rankings of Programs Increased Perceived Brand Value Increased Alumni Affinity	Employee of the Month Team Celebrations Time With Leaders Promotion Leadership Opportunities
Money	Univ: Financial Aid Co-Op: Earnings ROTC: Scholarship SMART: Scholarship	Increased Revenue External Process Investments External Direct Reimbursements	Salary Increases Bonuses Perquisites Training for Advancement

Note: The value of any of the above incentives depends on the characteristics of the person or organization.

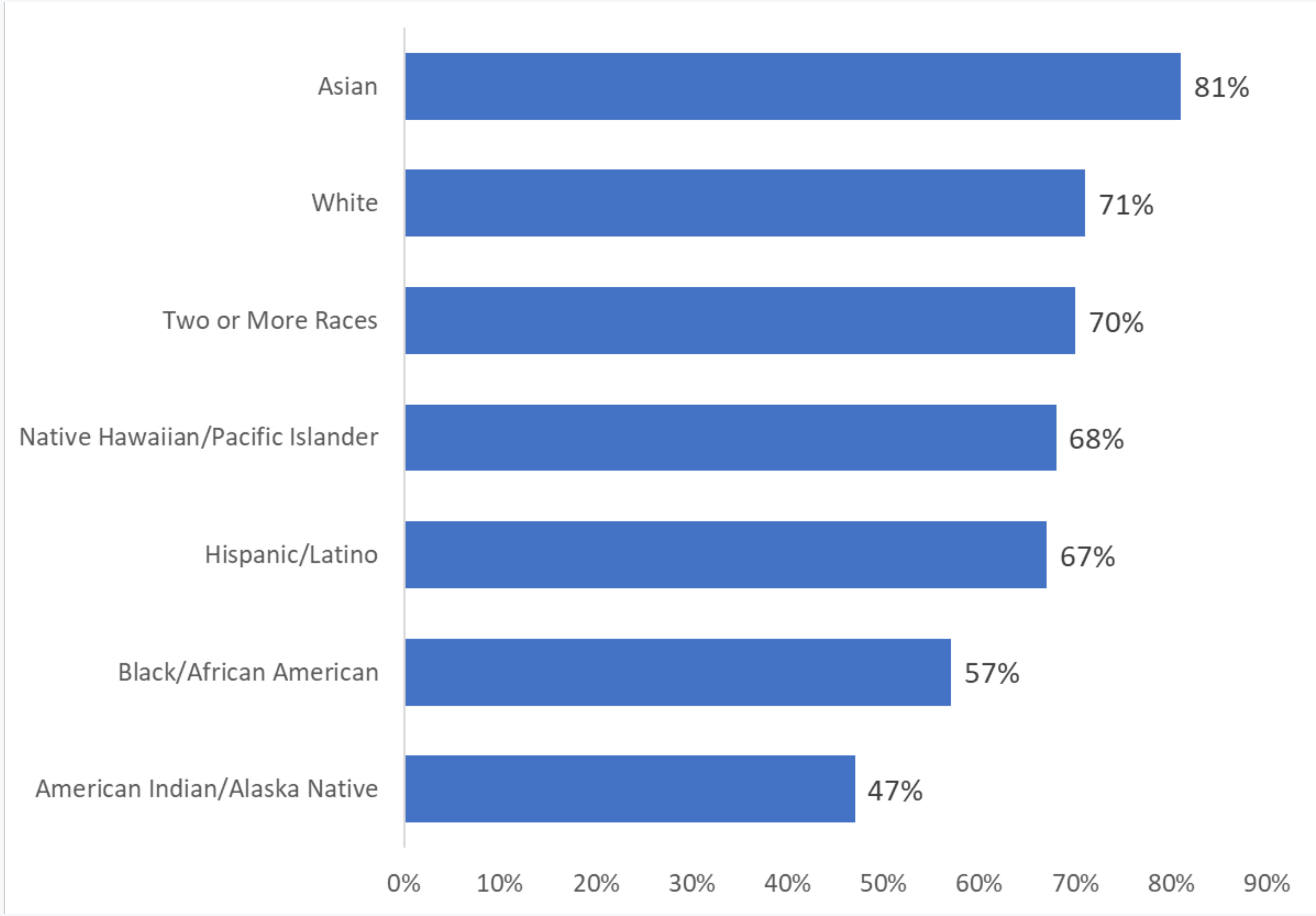
Student Recruitment & Retention

- K-12 Science & Math Course Preparation
- Factors Affecting STEM Retention
- Remediating Factors Affecting Retention
- SD Model of STEM Recruitment, Retention & Graduation

K-12 Science & Math Course Preparation

- **Limited access to high-level math and science courses:** Nationwide, only 50% of high schools offer calculus, and only 63% offer physics.
- **Significant lack of access to other core courses:** Nationwide, between 10-25% of high schools do not offer more than one of the core courses in the typical sequence of high school math and science education — such as Algebra I and II, geometry, biology, and chemistry.
- **Access by ethnicity:** 57% of Black students have access to a full complement of math and science courses (Algebra I & II, Geometry, Chemistry, Calculus and Physics) and 67% of Hispanic students have full access.

Students with Access to Full Range of Math and Science Courses, by Race and Ethnicity



Factors Affecting STEM Retention

- Student Aptitude – High School GPA & SAT scores
- Student Preparation – courses & experiences
- Class Size – in early math, chemistry & physics courses
- Quality of Teaching
- Quality of Advising
- Quality of Tutoring
- Higher Grades in Non-STEM Courses

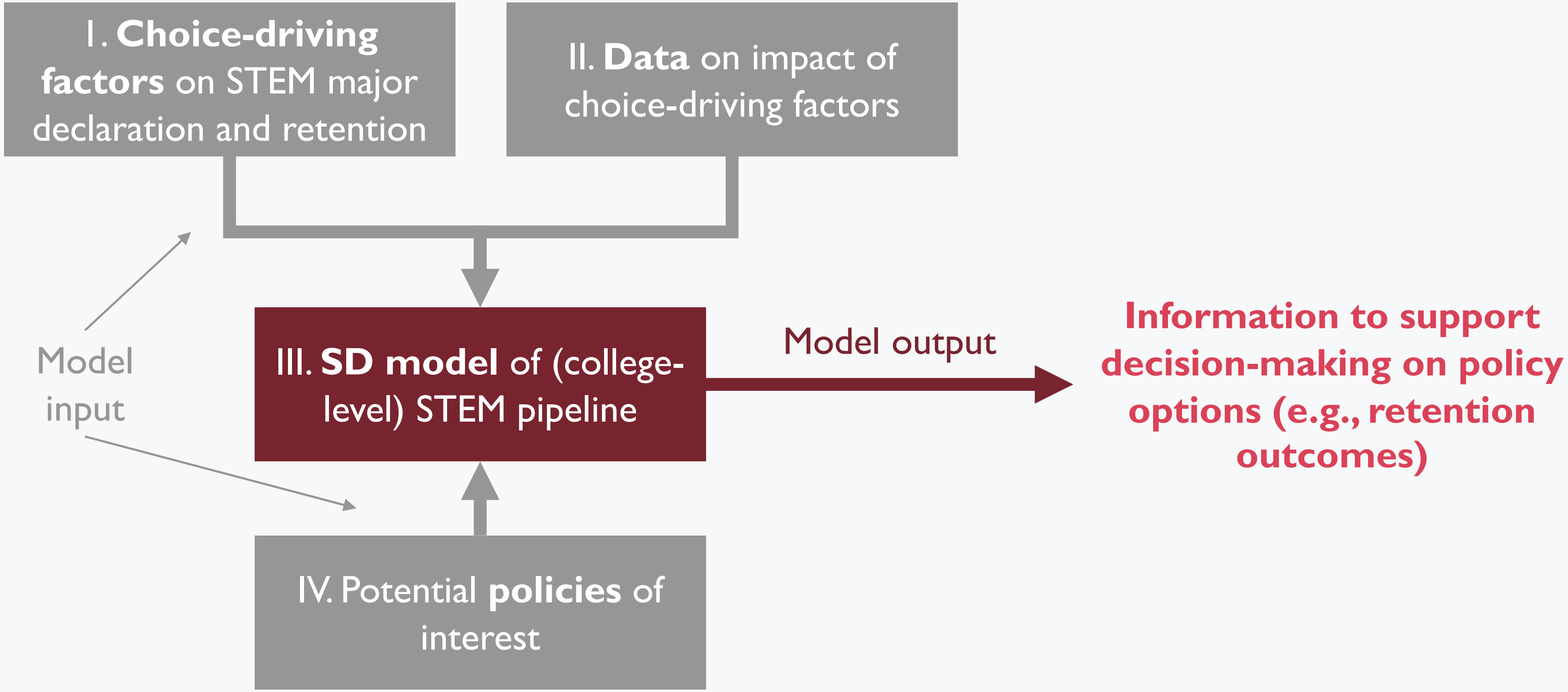
Remediating Factors Affecting Retention

Factor	Policy Remediations
Student Aptitude	Invest in incentives to attract high aptitude students
Student Preparation	Invest in high school course offerings & STEM experiences
Class Size	Invest in smaller classes; set standards to receive funding
Quality of Teaching	Invest in teacher training; set standards to receive funding
Quality of Advising	Invest in advisor training; set standards to receive funding
Quality of Tutoring	Invest in tutor training; set standards to receive funding
Higher Grades in Non-STEM	Increase emphasis on course rank rather than course grade

Factors Affecting STEM Retention – Cont.

- Parents actively engaged in their child’s education. Parent education level.
- Elementary and secondary school systems providing bread and depth curriculum for math and science courses.
- Elementary and secondary school instructors certified and credentialed to teach math and science courses.
- Increased opportunities to participate in summer STEM focused camps.
- High school Grade Point Average in Math & Science Courses.
- High school College and Career Counselors.
- Enrollment in Advance Placement STEM Courses: Biology, Chemistry, Calculus, Statistics and Computer Science.
- Direct admit into the university STEM major.
- Opportunities to participate in faculty research sophomore year.
- Mentoring from a faculty member with similar characteristics.
- Prospects for internships and apprenticeships during high school and college.
- Financial aid that covers the full cost of attendance.
- Academic advising, tutors, mental health and wellness services.

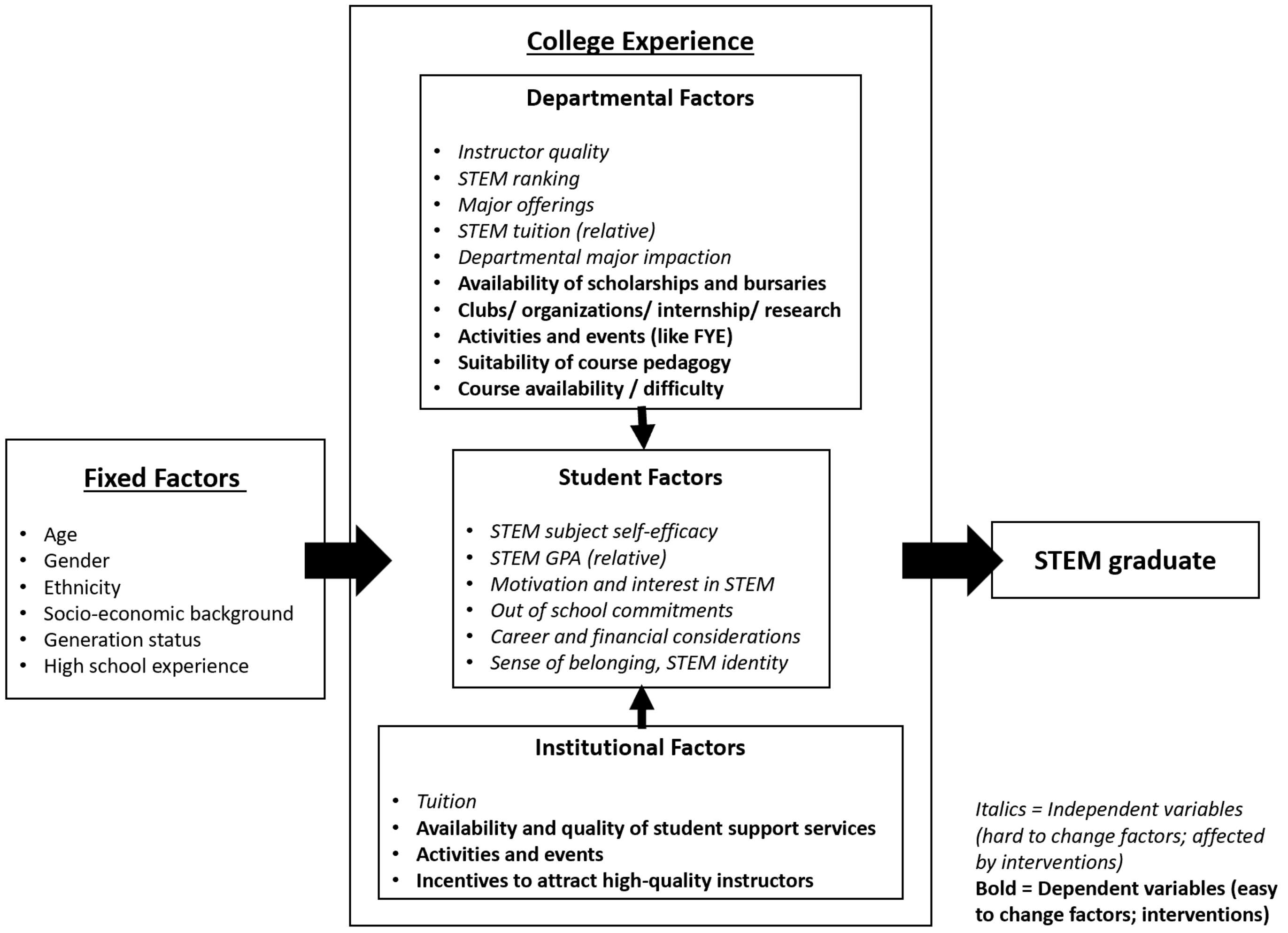
Using System Dynamics (SD) Modelling to Support Policy Testing and Innovation



I. Conceptual Model of College Retention Factors

College retention affected by:

- **Fixed** factors (e.g., gender, ethnicity, parents' educational background) → can't be changed
- **Student** factors (e.g., self-efficacy, student GPA) → hard to change directly, but can be affected by interventions
- **National, departmental,** and **institutional** factors (e.g., financial support, activities and events) → many directly inform **interventions**



Adapted from Harris and Wood, 2016 and Main et al., 2022.

II. Data on Impact Factors

- Longitudinal datasets on factors affecting STEM major declaration and retention → conduct **regression analysis to find correlation size**
  - High School Longitudinal Study of 2009 (HSLS:09)
  - Beginning Postsecondary Student Longitudinal Data (BPS)

- Literature on impact of (a) student factors and (b) policy interventions on STEM major declaration and retention → conduct **meta-analysis to find suitable correlation coefficients**

II. Example – Top 20 Factors on STEM Major Declaration from Regression Analysis on HSLS:09 Data

Variables of Significance	Regression Coefficient	Std. Error
STEM Course Taken	**0.316*** **	**(0.099)**
STEM GPA	0.115**	(0.048)
Overall GPA	-0.110**	(0.055)
Asian American/Asian	**0.108*** **	**(0.039)**
Parent has Bachelor's Degree	0.105*	(0.059)
11th Grade Science Identity Index	**0.083*** **	**(0.011)**
Parent has Associate's Degree	0.081	(0.059)
STEM GPA > Overall GPA	**0.075*** **	**(0.026)**
Science Utility Index	**0.059*** **	**(0.011)**
Parent is a High School Graduate	0.057	(0.057)

Variables of Significance	Regression Coefficient	Std. Error
Parent has Master's Degree or Higher	0.054	(0.060)
Parent has STEM degree	**0.053*** **	**(0.017)**
Free/Reduced Price Lunch	0.052*	(0.031)
SAT Math Score	0.051*	(0.030)
Urbanicity: Rural	**0.048*** **	**(0.014)**
11th Grade Math	**0.048*** **	**(0.016)**
SAT Reading Score	-0.047*	(0.025)
School Climate Index	0.046*	(0.024)
Women	-0.045	(0.017)
Percentage of URM Students	0.041**	(0.021)

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; $N = 11570$ (sample sizes have been rounded to the nearest 10)
Data source: U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09), Second Follow-up, 2016.

III. SD Model – Key Objectives

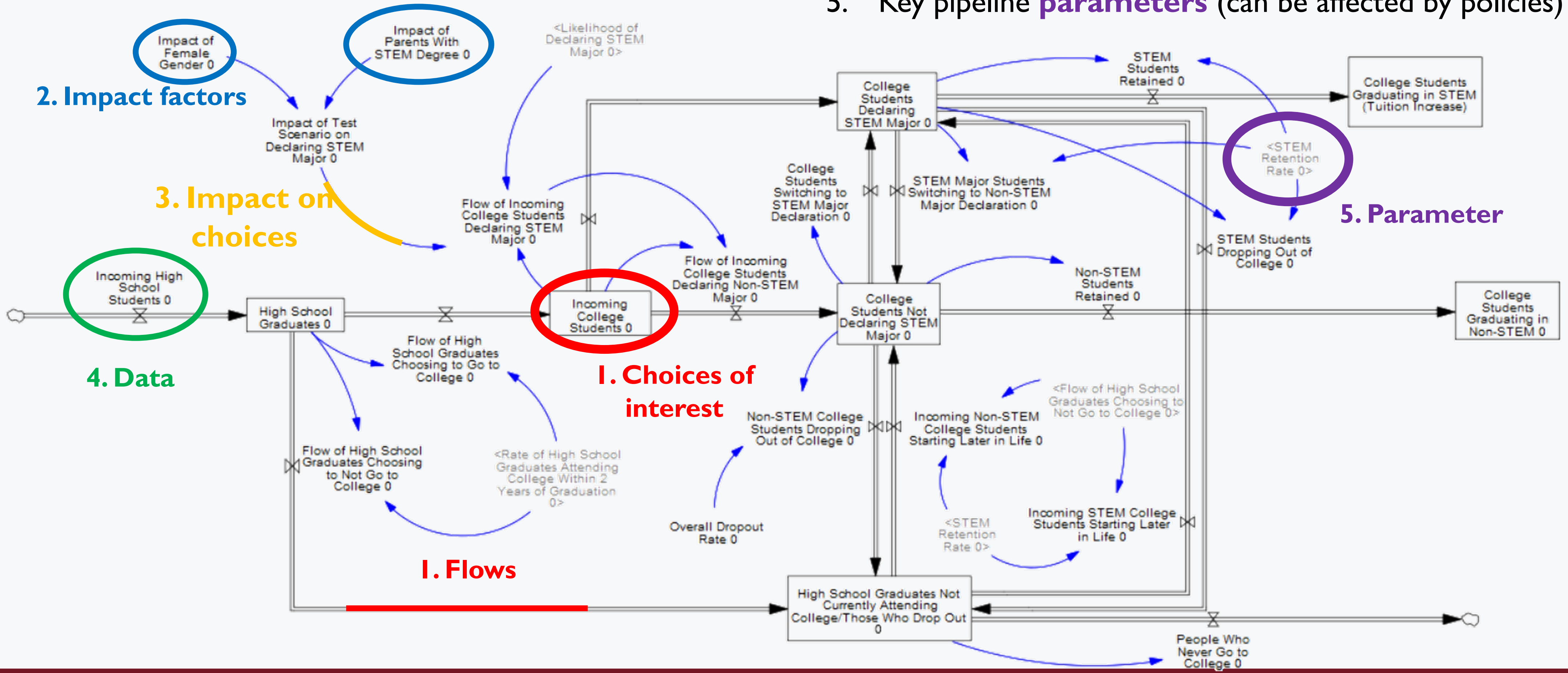
- Enable investigation of college STEM pipeline retention rates and output over time through **causal loops**
  - Models **flows** of high school grads to post-high school paths, and flows between different post-high school paths
  - Models **impact factors** that affect flows
  - Able to incorporate real **data** (e.g., regression analysis of longitudinal survey data, impact factors from literature)

- Enable **exploration of potential policies** and initiatives that affect retention outcomes

- Identify **high-impact** interventions

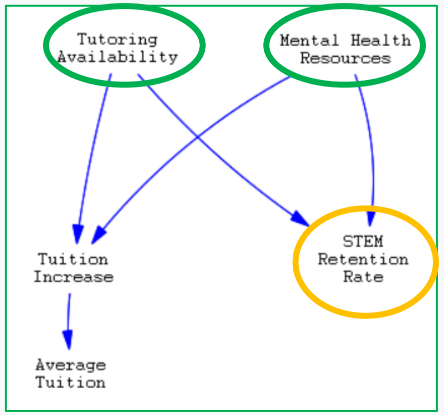
III. SD Model – Overall Structure

1. **Flows** of high school graduates to post-high school **paths**, and flows between different post-high school paths
2. Potential **factors that impact flows**
3. Qualitative and quantitative **impact of various factors on choices** for different flows
4. Real **data** from studies, surveys, regression models.
5. Key pipeline **parameters** (can be affected by policies)



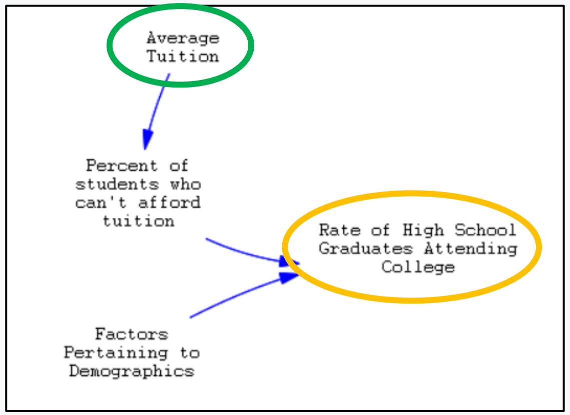
IV. Testing Potential Policies Using the SD Model

- The SD model provides a **relative quantitative evaluation** of the importance of each factor and intervention
- Policies and initiatives can directly affect some factors (e.g., reduction in tuition), which in turn affect students' choices and flows



Factors directly affected by policies & initiatives

Indirect factors that feed into overall pipeline model



- Running scenarios with **stochastic data** and different **combinations of policies** can identify the (a) most critical factors, and (b) most effective interventions on retention rates

Next Steps – Incorporate Priority Factors and Interventions

- Add causal loops for new interventions:
  1. **Practical experience** exposure (e.g., internships, apprenticeships, research projects) – raises student interest and self-efficacy
  2. Financial support in the form of **scholarships/fellowships** – lowers financial burden, raises opportunity cost of dropping out
  3. Opportunities for **informal learning** (extra-curricular clubs, competitions) – raises student interest and access to peer support
  4. **Industry-led events** (e.g., workshops) – raises student awareness and interest

- Effect sizes will be supported by a meta-analysis of the literature wherever possible

STW Education & Training

Although increasing college STEM participation and graduation is first priority in this analysis, a key question addresses that arises is the prior and related development of a Skilled Technical Workforce from students leaving high school without college aspirations or from other adults in the workforce.

- Every State seeks to develop this workforce pool especially from those high school graduates not destined for college but who leave with an aptitude for training in a wide range of STW occupations.
- Each State's requirements differ because most state programs for STW are focused on the immediate needs of local and regional industries.
- Moreover, most state STW programs respond both state and industry organized STW training initiatives and the multiple funding sources from state and private sources.
- The variation in these programs is wide and their structure and operation varies greatly depending on state policies and experience and the STW needs of local/regional industries.

Our report identifies Six Critical Elements for driving success although considerable subsequent research required to further develop these elements

SIX KEY ELEMENTS FOR STATE STW TRAINING PROGRAMS

Establish collaborative ecosystem for skilled technical workforce

Create the governance and structure model for the program
Define the roles and responsibility for state government, industry, other support organizations

Establish a consistent funding model

Occupational workforce training programs are expensive
Require consistent and reliable sources of funding to support training, equipment, and technology over time

Establish critical relationships between education providers and industry

Industry defines needed job type with specific workforce skills and competencies
Educators embed skills/competencies in the curriculum, internships, apprenticeships, and demonstrated student learning outcomes

Establish the strategic focus to institutionalize skilled technical workforce programs.

Workforce demand and supply are specific to industry requirements
Industry must clearly define the job types by classification, level of experience/skills, number needed currently and in the future
Education providers must be clear about their capacity to produce the trained workforce

Establish a target workforce to institutionalize skilled technical workforce programs.

Most state efforts with occupational training programs are designed for entry level positions
Recent years see expansion in retraining and upskilling programs for mid-level positions in manufacturing technology and robotics

Establish training evaluation measures

Necessary constant evaluation to determine whether the training programs are meeting the needs of industry and the individual

Next Steps

- State of the K-12 Ecosystem
- Evidence Base for Transformation
- Incorporate priority factors and interventions into SD model
- STW Next Steps – Integrate Into WRT-1055

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