Mountain View Whisman School District

Measure G & T Summary & Background

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Section 1

Measure T and G Lessons Learned

MVWSD has been fortunate to have community support for the passage of two bonds in recent years. Both bonds have accomplished many needs that needed to be addressed. Our District has grown in our approach to how we take on major capital projects. Public support will continue to be needed as we manage growth in our District.

Measure G Passage

On June 5, 2012, 67.58% of local voters passed Measure G, which generated funding to provide safe, efficient, and modern facilities for Mountain View Whisman School District students and staff. The approval percentage was the highest in Santa Clara County and the 4th highest of the 34 school bond measures in the State of California.

Measure G generated $198 million to repair, upgrade and expand our local schools. The Student Facility Improvement Plan outlined priorities and projects. In total, $422,696,749 million in needs were identified. Measure G was not capable of addressing all the needs of the District. It did not include construction of Castro, Stevenson, Vargas and the DO were built.

Measure G Lessons Learned

Lesson 1

Developing a project list avoids costly delays

- Measure G was passed in 2012 but construction didn't start in earnest until 2015.
- Time lag costs approximately 5% a year in inflation costs.

Lesson 2

Having a priority list ensures that needed projects are accomplished

- Tier 1 items such as electrical, lighting, safety items (fencing and fire alarm upgrades) were not completed due to cost overruns under Measure G.
- Projects that were not high on the priority list were tackled first including the auditoriums, innovation centers, fields, and libraries (Tier 3).
- Kitchens were replaced at all school sites as opposed to being modernized (Tier 2).

Lesson 3

In an effort to address the previous two lessons, and in an effort to stay in line with what MVWSD advertised both in its MFP and in the information that was sent to community members, the BOT voted on set of priorities which requires a supermajority for alterations (four votes needed to reopen debate of the priorities and three votes to approve new direction).

- Some of the projects were not envisioned by the former SFIP in their finished form (see above).
- Board meeting time was spent debating specific projects and line items in budgets which led to overruns and took the focus away from teaching and learning.

Measure T

Measure T passed with a strong 69.50% of voter support. Measure T was passed to provide safe and modern learning environments for our current and future students. A Master Facility Plan was adopted by the board in 2019 to guide the work of the bond measure, which allowed staff to tackle projects as soon as the measure was passed in 2020.

Measure T Lessons Learned

Realized that we could manage the bond more efficiently. Our approach is that a construction project should not be controversial.

Lesson 1

- Cost of construction will rise. To maximize the public's money, we needed to move with urgency. Additional funding of $18,130,000.00 in the first year due to avoiding approximately 7% construction inflation.

Lesson 2

- Things that should have been done earlier were missed (HVAC, plumbing, lighting, etc). We asked the Board to approve a project priority list based on the parameters set out in the Master Facilities Plan. All Measure T construction is driven by the updated MFP and the project priority list with safety and efficiency projects being the highest priority. A few projects were added due to safety concerns.

Lesson 3

- The public was critical of the lack of transparency of projects during Measure G. There has been no campaigning for specific needs with Measure T. The priority tiers in the MFP has helped build trust with transparency. No citizens at board meetings concerned about cost overruns.

We are on track to accomplish everything we have advertised that we would do under Measure T.

Measure T (passed 2020) infographic	Measure G (passed 2012)
Ballot Language: To provide safe/modern classrooms, arts/science labs at neighborhood schools for quality education; relieve student overcrowding; replace aging roofs, inefficient heating/ventilation systems; upgrade, acquire, construct classrooms, facilities, sites/equipment; shall Mountain View Whisman School District's measure authorizing $259,000,000 in bonds at legal rates, levying $30/$100,000 assessed value ($18,600,000 annually) while bonds are outstanding, with independent oversight, audits, no funds for administrators, all funds controlled locally for Mountain View schools, be adopted?	Ballot Language: To protect quality education in Mountain View, provide safe and modern classrooms, and make schools operate more efficiently, shall the Mountain View Whisman School District remove hazardous lead/asbestos materials, improve earthquake safety, upgrade fire alarms/security, replace outdated and inefficient plumbing/electrical/heating/ventilation, update computers/technology, and upgrade, acquire, construct schools, sites, facilities and equipment by issuing $198 million in bonds at legal rates, with independent oversight and all funds spent on local elementary and middle schools?

Summary list of Measure G [- link]

Measure G Project	Priority	Bubb	Castro (2)	Imai	Landels	Monta Loma	Stevenson (2)	Theuerkauf	Slater (Existing at time of MFP)	Crittenden	Graham	Corp Yard Crittenden	Corp Yard Graham
Building Structural Updgrade	1		Complete					Not completed		Complete	Complete		
Restroom Modernization (code compliance, nurse restroom)	1	Complete	Complete	Complete	Complete	Complete	Complete	Complete	No	Complete	Complete		
Building Accessibility (counters, sink cabinets, thresholds)	1	Complete	Complete	Complete	Complete	Complete	Complete	Complete	No	Complete	Complete		
Kindergarten Classrooms (code updgrade, add RR, reconfig. & expansion)	1	Complete						Complete					
Kindergarten Classroom Replacement	1	Complete	Complete		No	No	Complete	No					
Classroom Replacement - One Story	1	No	Complete	No	No	No	Complete	No	No	No			
Classroom Replacement - Two Story	1	No	Complete	No	No	No	No			Partial	Partial		
MUR Building Replacement	1	Complete	Complete	Complete	Complete		Complete						
Preschool Classroom Replacement	1		No										
Fire Alarm System Upgrade	1	Complete	Complete	Complete	Complete	Complete	Complete	Complete	No	Complete	Complete		
Electrical Upgrade	1					No	Complete	No	No	No	No		
Campus Lighting	1	No	No	No	No		No	No	No		No		
Separate Parking, Pick-up and Bus Loading Areas	1	No	Complete	No	No	No	No	No	No	No	No		
Site Accessibility Updgrade (Ramp Replacement)	1			Complete									
Gas Updgrade	1	No	No	Complete	No	No	No	No	No	No	No		
Signage, drinking fountains	1	Complete	Complete	Complete	Complete	Complete	Complete	Complete	No	Complete	Complete		
Kindergarden Play Cluster (AC, turf and play structures)	1	No	Complete	No	No	No	Complete	No					
Designated Play Structures (Grades 1-3, 4-5)	1	No	Complete	No	No	No	Complete	No	No				
Preschool Play Cluster	1		No					No					
Technology (Communication, Data, Phone)	1	Partial	Complete	Partial	Partial	Partial	Complete	Partial	No	Complete	Partial		No
Fencing	1	No	No	No	No	No	No	No	No	No	No	No	No
Demolition of Existing Buildings	1	Partial	Yes	Partial	Partial	No	Complete	No	No	Partial	Partial	Complete	No
Modernization of Existing Classrooms	2	Complete	Complete	Complete	Complete	Complete	Complete	Complete	No	Complete	Complete		
Modernization of Existing Library	2		Complete			No	Complete	No			Complete		
Modernization of Existig MUR	2					Complete		Complete		No			
Modernization of Existing Admin	2	Complete	Complete	Complete	Complete	Complete		Complete	No		Complete		
Modernization of Existing Kitchens	2									No	No		
Mechanical Updgrade	2	No	No	No	No	No	Complete	No	No	No	No		
Plumbing Updrades	2	Partial	Partial	Partial	Partial	Partial	Complete	Partial	No	Partial	Partial		
Security System Updgrades	2	No	No	No	No	No	No	No	No	No	No		
EMS Updgrades (Site and building incl. ext. light connection, auot controls)	2	Partial	Partial	Partial	Partial	Partial	Partial	Partial	No	Partial	Partial		
Underground Utility Survey/Upgade	2	No	Complete	No	No	No	Complete	No	No	No	No		
Hard Court Play Area (new AC, AC Overlay)	2	No	Complete	No	No	No	Complete	No	No	No	No		
Covered Walkway Repair	2	No	No	No	No	No	No	No	No	No	No		

Shaded Boxes indicate work not identified on MFP

Section 2

Current Measure T Projects and Status and Options

Measure T Project	Priority	Status
HVAC Replacement	1	In process
Permiter Controls (Security Fencing - all sites except Monta Loma)	1	Complete
Access Control Project (Electronic Locks)	1	In process
Surveillance Cameras	1	Complete
Outdoor Learning/Landscaped Areas	2/3	In process
Site Lighting	1	Complete
Storage Buildings (Stevenson and Vargas)	1	Complete
Park Restrooms (Castro, Imai, Landels)	1	In design/permitting
Window Replacement	1	In process
Paving and Utility Work (Bubb, Castro, Crittenden, Imai, Theuerkauf)	1/2	Complete
Crittenden Middle School Public Address System	1	Complete
Landels New Classroom Building	1	Project on hold
Bottle Fillers	1	In process
Solar Shade Structures	1	Complete
Imai Portable Classroom Building	1	Complete
Theuerkauf New Main Switchboard	1	In process
Crittenden Upgrade Main Switchboard	1	Complete
Landels Playground Surfacing	1	In design/permitting
Mistral Administation Remodel	2	Complete
Crittenden Marquee	-	Complete
Vargas Marquee Relocation	-	Complete
Crittenden and Graham Painting	-	In process
Counseling Rooms	-	for consideration
Districtwide Public Address Speakers - Small Offices	-	In process

All priority one projects have been completed or are in progress or in design. Projects such as the two story building at Landels and fencing at Monta Loma have been put on hold.

Measure T: Unallocated funds $12,933,927.65 to be assigned.

Measure T: The below is a list of possible Priority 2 projects with scope and current estimate minus some Priority 2 projects that were removed from the original Master Facility Plan after discussions with the Director of MOT and Technology. These facilities needs were met in other ways.

Priority 2 Project Options. Link

Site	Project	Details	Scope of Work	Estimated Cost (Per Artik MFP Update)	Current Conceptual Estimate
Bubb	Technology Upgrade	Replace Fiber Optic and Copper Cable Networks	Replace Fiber and Copper between MDF (bldg. 2) to Bldgs. 1, 3, 4, 5, 6, MUR and P1. New Fiber to be OM4 and Cooper to be Cat6A	$ 142,300	$ 142,300
Bubb	Roof Repair	Roof Repair at Bldgs. 1, 2, 3, 4, 5, 6.	Repair damaged membrane, pipe flashings/storm collars, gutters/drain assemblies	$ 550,500	$ 975,000
Bubb Total				**$ 692,800**	**$ 1,117,300**
Castro	Add Covered Walkway to Upper Level Corridor	Add Covered Walkway to Upper Level Corridor	New canopy over upper level walkways, columns down to ground level	$ 1,605,200	$ 1,605,200
Castro Total				**$ 1,605,200**	**$ 1,605,200**
Imai	Technology Upgrade	Replace Fiber Optic and Copper Cable Networks	Replace Fiber and Copper between MDF (bldg. 1) to Bldgs. 2, 3, 4, 5, 6, MUR and P1. New Fiber to be OM4 and Cooper to be Cat6A	$ 108,700	$ 125,000
Imai	Roof Repair	Roof Repair at Bldgs. 1, 2, 3, 4, 5, 6.	Repair damaged membrane, pipe flashings/storm collars, gutters/drain assemblies	$ 527,500	$ 975,000
Imai Total				**$ 636,200**	**$ 1,100,000**
Landels	Replace Kinder Playground	Replace existing K Playground Equipment and play surface	Replace K Play Equipment and install turf surfacing.	$ 342,800	$ 462,000
Landels	Technology Upgrade	Replace Fiber Optic and Copper Cable Networks	Replace Fiber and Copper between MDF (bldg. 1) to Bldgs. 2, 3, 4, 5, 6, and MUR. New Fiber to be OM4 and Cooper to be Cat6A	$ 108,700	$ 108,700
Landels	Roof Repair	Roof Repair at Bldgs. 1, 2, 3, 4, 5, 6.	Repair Damaged Membrane, pipe flashings, storm collars and gutter/drain assemblies	$ 519,500	$ 975,000
Landels Total				**$ 971,000**	**$ 1,545,700**

Mistral	Drinking Fountains	Replace aged drinking fountains with new bottle fillers	Replace 2 existing fountains with bottle fillers	$ 51,300	$ 51,300
Mistral	Roof Repair	Replace Roofing, gutters and pipe flashings	Full Roof Replacement at Buildings H, J, K, L, N, P	$ 2,239,800	$ 2,239,800
Mistral Total				**$ 2,291,100**	**$ 2,291,100**
Monta Loma	Utility Survey and Repair	Survey and test all domestic water, sanitary sewer, storm drain and gas line and repair deficiencies	Replace 25% of underground utility systems	$ 523,800	$ 523,800
Monta Loma	Repave Existing Staff Parking	New Asphalt paving and striping of staff parking lot.	Staff parking lot adjacent to Bldgs. A, C, E, L	$ 509,000	$ 509,000
Monta Loma	Restroom Modernization	Add gender neutral restrooms (students/staff)	Add four (4) gender neutral single occupancy restrooms.	$ 318,500	$ 1,200,000
Monta Loma Total				**$ 1,351,300**	**$ 2,232,800**
Stevenson	Outdoor Landscaped Area	Add Landscape and outdoor furnishings	Covert area to 70% hardscape, 30% softscape and add outdoor furnishings and connectivity (benches, seatwalls, tables, electrical/data)	$ 5,610,000	$ 3,200,000
Stevenson	Technology Upgrade	Replace IDF cabinet in Library with larger cabinet.	Replace IDF cabinet in Library with larger cabinet (Building E).	$ 64,100	$ 64,100
Stevenson Total				**$ 5,674,100**	**$ 3,264,100**
Theuerkauf	Kinder Playground Replacement	Replace Kinder Playground Equipment and Surfacing	Replace Kinder Play Equipment, Install turf surfacing and repaving. 70% softscape and 30% hardscape	$ 896,100	$ 896,100
Theuerkauf	Utility Survey and Repair	Survey and test all domestic water, sanitary sewer, storm drain and gas line and repair deficiencies	MFP Update assumed repair/replacement of 25% of underground utilities	$ 1,354,000	$ 750,000
Theuerkauf	Technology Upgrade	Replace Cabling from Bldg. A to B, C, D, E, F, G and H	Replace fiber cabling between MDF (bldg. A) to Bldgs. C-H, P1-P4 and add interior cabling to WAPs and TVs in classrooms	$ 188,600	$ 350,000
Theuerkauf	Replace playground Grades 1-5	Replace Play Equipment and surfacing at playground	Replace play equipment and surfacing	$ 334,900	$ 562,800
Theuerkauf	Roof Repair	Roof Repair at Bldgs. A, C, D, E, F, G and H.	Repair Damaged Membrane, pipe flashings, storm collars and gutter/drain assemblies	$ 606,000	$ 606,000
Theuerkauf	Restroom Modernization	Replace Fixtures and Finishes	New Restroom Fixtures (sinks, dispensers, WC) and new floor, wall and ceiling tiles	$ 607,700	$ 607,700
Theuerkauf Total				**$ 3,987,300**	**$ 3,772,600**
Crittenden	Utility Survey and Repair	Survey and test all domestic water, sanitary sewer, storm drain and gas line and repair deficiencies	MFP Update assumed repair/replacement of 75% of SS, 50% of SD, 25% of DW, 25% of gas pending survey results	$ 3,446,400	$ 1,500,000
Crittenden Total				**$ 3,446,400**	**$ 1,500,000**
Graham	Classroom Modernization	Modernize Arts building for Industrial Arts and Home Economics	Modernize four (4) classrooms in units 5 & 6 to create lab-type spaces for woodshop (electrical and ventilation), home economics (kitchens) and art lab type spaces	$ 4,510,000	$ 4,510,000
Graham	Roof Replacement	Replacement of roofing at Buildings 12 & 13	Full replacement of roofing and gutters/downspouts at Units 12 and 13	$ 1,378,500	$ 1,378,500
Graham	Technology Upgrade	Replace cabling in classrooms	Replace copper cabling between MDF (Bldg. 9) and buildings 1-17. Add one copper drop to each TV/Front Row location in classrooms (46 locations)	$ 135,900	$ 275,000
Graham Total				**$ 6,024,400**	**$ 6,163,500**

Total of priority 2 items at all sites				**$ 26,679,800**	**$ 24,592,300**
Other Projects as identified (but not noted on MFP)					
Crittenden	Roof Replacement	Replacement of shingle roofing at Bldgs. 100, 200, 300, 500, 700, 900, 1000	Replacement of Roofing, gutters, downspouts and pipe jacks/flashing	$ 3,150,000	$ 3,150,000
Montecito Preschool	Montecito Preschool Conversion	Conversion of existing portable classrooms to preschool classrooms	Includes addition of single occupancy restrooms to each of the ten (10) portables. New play area/yard and fencing. Includes modernization of existing administration building.	$ 3,271,268	$ 3,271,268
Graham Middle School	Public Address system	PA is currently old Bogen System, convert to Front Row to match other sites.		$ 225,800	$ 225,800
Stevenson	Public Address system	PA is currently old Bogen System, convert to Front Row to match other sites.		$ 172,500	$ 172,500
Bubb/Huff/Landels/Theuerkauf/Castro/Stevenson/Vargas MUR.	Projectors	Install permanent projector at Multi-Use Rooms to replace units currently on mobile carts		$ 875,000	$ 875,000
Other Project Totals				**$ 6,421,268**	**$ 7,694,568**
Grand Total of all Priority 2 projects plus other projects identified				**$ 33,101,068**	**$ 32,286,868**

Process for Assigning Measure T Unallocated Funds

In August staff will present an update on summer construction and ask for board guidance on additional projects to expend the remainder of Measure T. Staff will make recommendations based on safety and efficiency.

Section 3

White Paper Science Labs

White paper: Adequacy of science classrooms in MVWSD: Issued to Trustees Sept, 2021

As of late, several Trustees have mentioned that they would like to add science classrooms into the scope of work for Measure T. While no other instructionally tied item, excluding the building of classrooms to adjust for growth, is listed as a priority one project, the repeated reference to inadequate science labs suggests that students are in classrooms that do not meet the needs of the curriculum. While staff appreciates the desire to exceed standards, and to create classrooms that are geared to the future, staff is noticing that the frequent reference of inadequate facilities to fulfill a possible “want” to create these types of classrooms is leading to confusion about the adequacy of our classrooms.

The introduction of Response to Instruction:
As part of strategic plan 2021, MVWSD first piloted and then implemented Response to Instruction. Prior to 2017, only the schools that had PTAs that could raise enough funds to pay for a “science teacher/coach” had dedicated classrooms for science instruction. Additionally, until 2017, every elementary teacher was required to teach science in their classroom. In 2017, MVWSD began the first year of its RTI pilot. During year one, only one elementary school (Bubb) used RTI for science instruction. During the 2018 school year, all elementary RTI classrooms became science classrooms.

Middle school classrooms have always met the state requirements for science. According to California building code https://www.cde.ca.gov/ls/fa/sf/title5regs.asp

Laboratories shall be designed in accordance with the planned curriculum.

1. Science laboratory:
    1. Size is at least 1300 square feet including storage and teacher preparation area.
    2. Science laboratory design is consistent with the requirements for proper hazardous materials management specified in both the "Science Facilities Design for California Public Schools," published by the California Department of Education, 1993, and the "Science Safety Handbook for California Public Schools(PDF)," published by the California State Department of Education, 1999.
    3. Accommodations are made for necessary safety equipment and storage of supplies; e.g., fire extinguisher, first aid kit, master disconnect valve for gas.
    4. Secured storage areas are provided for volatile, flammable, and corrosive chemicals and cleaning agents.
    5. Properly designated areas are provided with appropriate ventilation for hazardous materials that emit noxious fumes, including a high volume purge system in the event of accidental release of toxic substances which may become airborne.
    6. Exhaust fume hoods, eye washes, deluge showers are provided.
    7. Floor and ceiling ventilation is provided in areas where chemicals are stored.
    8. Room is provided for movement of students around fixed-learning stations.
    9. There is the capability for technology which complements the curriculum.
    10. Classrooms are flexibly designed to insure full student access to laboratory stations and lecture areas.

As you can see pictured below, middle schools have classrooms that are set up as lab rooms with preparation hallways for setting up science experiments. In each instance, the science classroom is designed to meet the needs of the curriculum. Middle School NGSS standards put a heavier emphasis on designing models, constructing that require more of a lab set-up. Example of a middle school NGSS standard: Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

In middle school there are more sinks and additional lab setups to accommodate larger classroom experiments, and students' exploration of the scientific method and its curriculum. Additionally, students are expected and allowed to handle various materials.

In elementary school, teachers' curriculum differs significantly from their middle school peers (see below). Unlike middle school teachers, elementary teachers are not content-area experts and their training is limited to the professional development that we offer. Typically, it's from our coaches, Science is Elementary and Discovery Education. Classrooms are outfitted with sinks, and other materials that are consistent with the experiments that they are conducting.

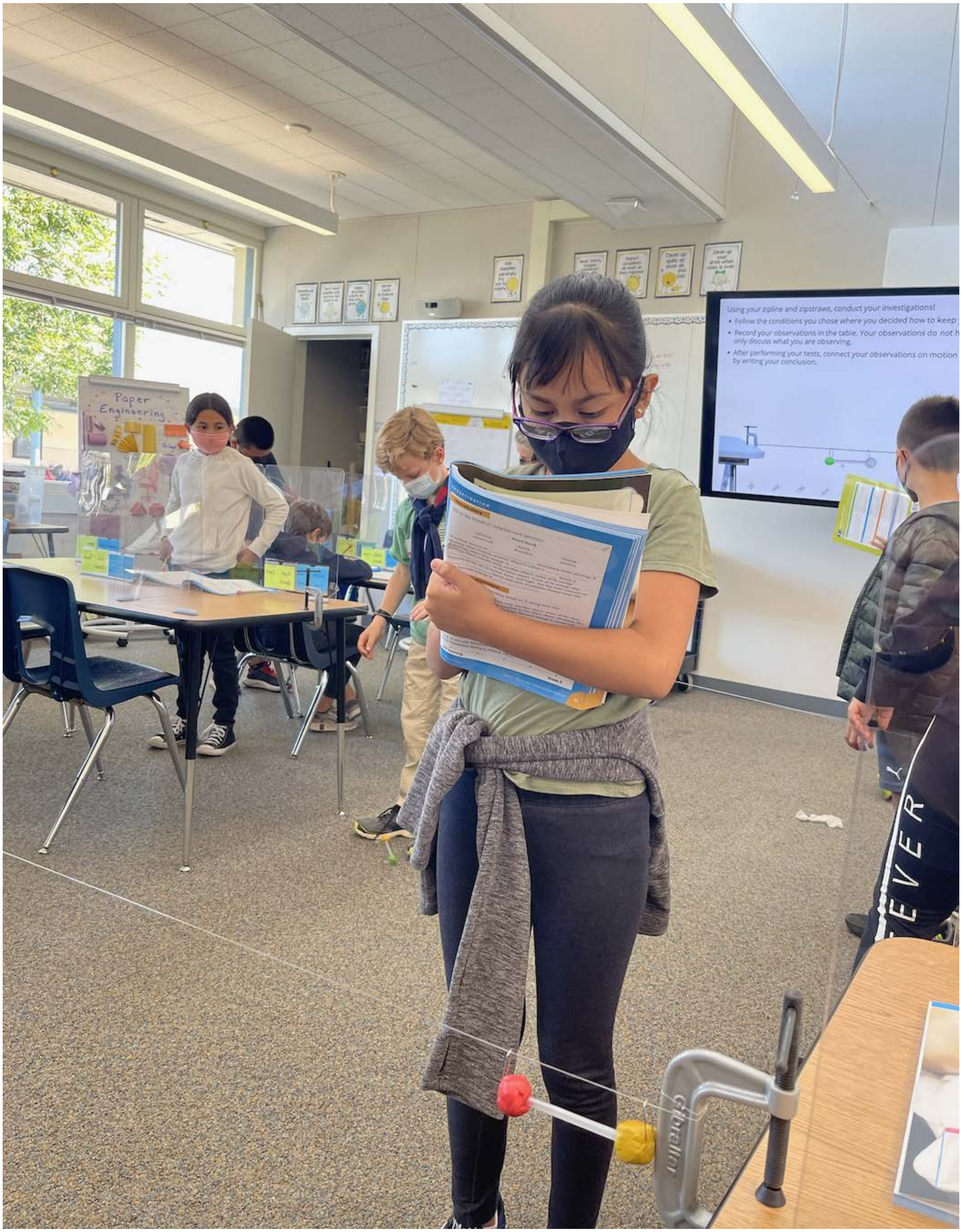
Last week, while conducting a site walkthrough, a Trustee and I had the opportunity to speak with an elementary RTI teacher. The teacher stated that they did not need science tables or a complete redesign of their classroom. Most of the activities can be conducted under their current environment. Instead the concern should be centered on making sure that each classroom has access to enough supplies (cups, microscopes, protective goggles, etc).

Even though our science curriculum provides science materials for each lab, we could do more to make sure that we have enough supplies so as to not require students to share. Additionally, we could invest in more storage options for RTI classrooms, as the equipment and materials for each classroom increases.

Pictures of Science classrooms:

Stevenson RTI classroom

Theuerkauf classroom



Mistral Classroom

Middle School Labrooms.

District Adopted Curriculum: TCI - Bring Science Alive

TCI- Bring Science Alive Units are designed around storylines and anchoring phenomenon to support NGSS standard learning and understanding.

Elementary Science Teacher Materials Include:

- Digital Subscription accessible via Clever
- Lesson Guide
- Vocabulary Picture Cards
- Lab Materials (aligned with each unit's focus and phenomenon)
    - TK/K- 2 boxes
    - 1st- 3 boxes
    - 2nd- 3 boxes
    - 3rd- 2 boxes (A sample 3rd grade lesson materials kit is linked here)
    - 4th- 5 boxes
    - 5th- 4 boxes
- A Refill Kit is also included for each class
- Students have Scientific Notebooks for note taking, recording investigation observations, etc.

TCI Curriculum Lessons and 5E Scientific Model:

- STEAM Teachers at MVWSD are engaging in using the 5E model with the TCI curriculum lesson sequence:

ENGAGE	EXPLORE	EXPLAIN	ELABORATE	EVALUATE
TCI Lesson Phenomenon	**TCI Lesson Exploration Activity**	**TCI Lesson Resources Used for Explanation and Examples**	**TCI Lesson Elaborate Activity**	**TCI Lesson Evaluate Component:** ***Write a proficient exit ticket***
Opens the learning task, accesses prior knowledge, and organizes student thinking toward outcomes of current activities	Students interact/experiment with phenomena to begin to develop concepts, processes and skills of new learning.	*Teacher formally provides definitions and new labels. Students explain new concepts and definitions in their own words. They use evidence from the*	What do you already know? Why do you think…? *Students use new vocabulary, definitions and explanations for new context/new*	Why do you think...? What evidence do you have…? What do you know about ___? How would you explain___? How would you answer this

		investigations/experiments (Explore) for explanations.	*situations.*	question? Teachers and students assess understanding of skills.

3rd Grade Sample Lesson:

Unit 2 - Forces and Motion

Teacher introduces the unit concept with a storyline and the anchor phenomenon at the beginning of the Unit.

Storyline:
The carnival is coming to town! Here, things move quickly. Find out how rides and games make objects move by exploring forces and motion in this unit.

Unit Anchoring Phenomenon:
Students watch a video and different kinds of motion at a carnival. Have you seen a bumper car ride? What happens if two bumper cars push against each other? What might happen if two bumper cars push against one bumper car?

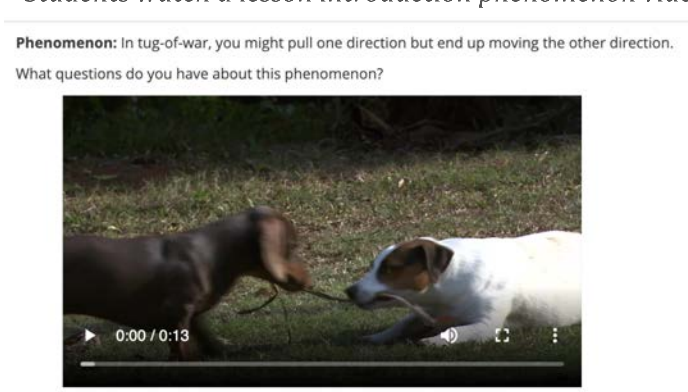
Materials included in the TCI Kit for this Unit are linked [here]

Lesson Focus : What Happens When Forces Are Balanced or Unbalanced?

NGSS Performance Expectation: 3-PS2-1

Lesson Phenomena: In tug-of-war, you might pull one direction but end up moving the other direction. **(ENGAGE)**

***Students watch a lesson introduction phenomenon video. Picture below*



Disciplinary Core Idea: Students may know that in a game of tug-of-war, you might pull in one direction but end up moving in the other direction. Using this knowledge, they investigate forces and motion and observe balanced and unbalanced forces through videos and a simulation. (PS2.A)

Cross Cutting Concept: Comprehending cause and effect, students predict how an object will move depending on whether the forces acting on it are balanced or unbalanced.

Science and Engineering Practice: Students conduct science investigations using fair tests in which variables are controlled by setting up an experimental spring scales and a pulley system.

Lesson related vocabulary: Teacher introduces vocabulary **-** balanced forces, unbalanced forces, gravity, friction.

Student Observation and Investigation: Students use a pulley, S-hooks, washers, weights to investigate balanced and unbalanced forces on an object. Each group uses the following materials from the TCI materials kit: **(EXPLORE)**

- A piece of string, about 60 cm long
- One pulley
- Two metal S-hooks
- 16 washers

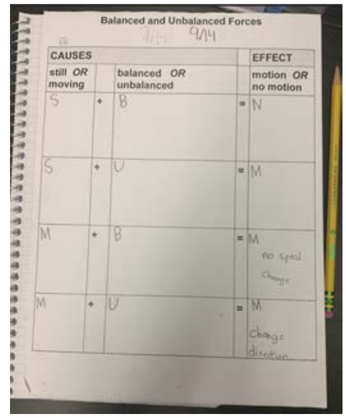
Investigation Set-Up: Teacher explains how to set up (clamp) the pulley system on the desks and use the balance with weights.

Student Investigating Situations: When the S-hooks are not moving, the forces are balanced. When the S-hooks are moving, the forces are unbalanced. **(EXPLAIN)**

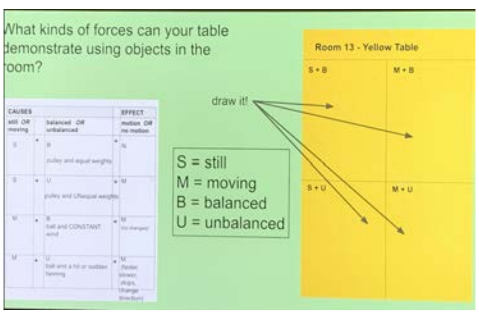
Student groups plan and conduct an investigation to gather evidence for these four situations.

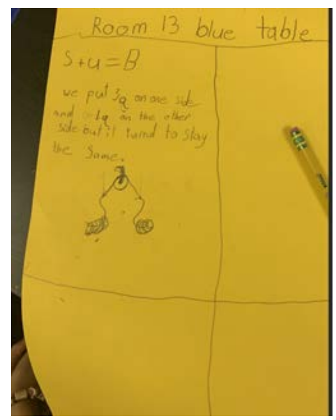
- What happens when **balanced** forces act on a **still** object?
- What happens when **unbalanced** forces act on a **still** object?
- What happens when **balanced** forces act on a **moving** object?
- What happens when **unbalanced** forces act on a **moving** object?

Student groups engage in four trials and record their data in a data table in their Interactive Science notebooks. Students make and support their claims **(ELABORATE)**



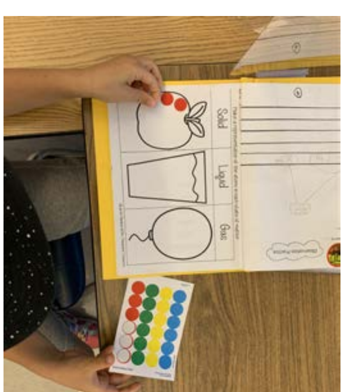
Independent Work/Check for Understanding: Each student in the investigative group is then asked to draw and explain the investigation situation that was conducted.

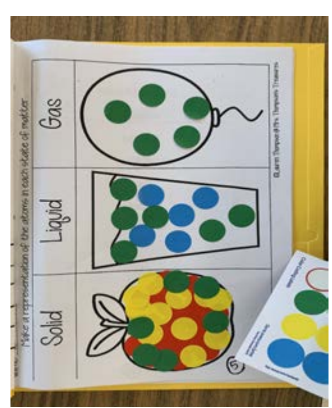


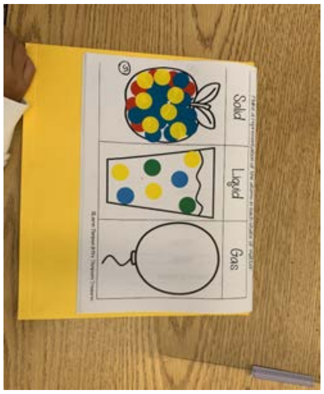


Lesson CLosure: Teacher reviews lesson phenomenon, key vocabulary used. Students complete an Exit Ticket to show their understanding. **(EVALUATE)**

Glimpses from hands-on activity and investigation with 2nd Grade STEAM Classroom Lesson on Solids, Liquids, and Gases: (*materials included in TCI Kits)*







2nd Grade STEAM Investigation to determine whether the mixing of two or more substances results in new substances: (*materials included in TCI Kits)*

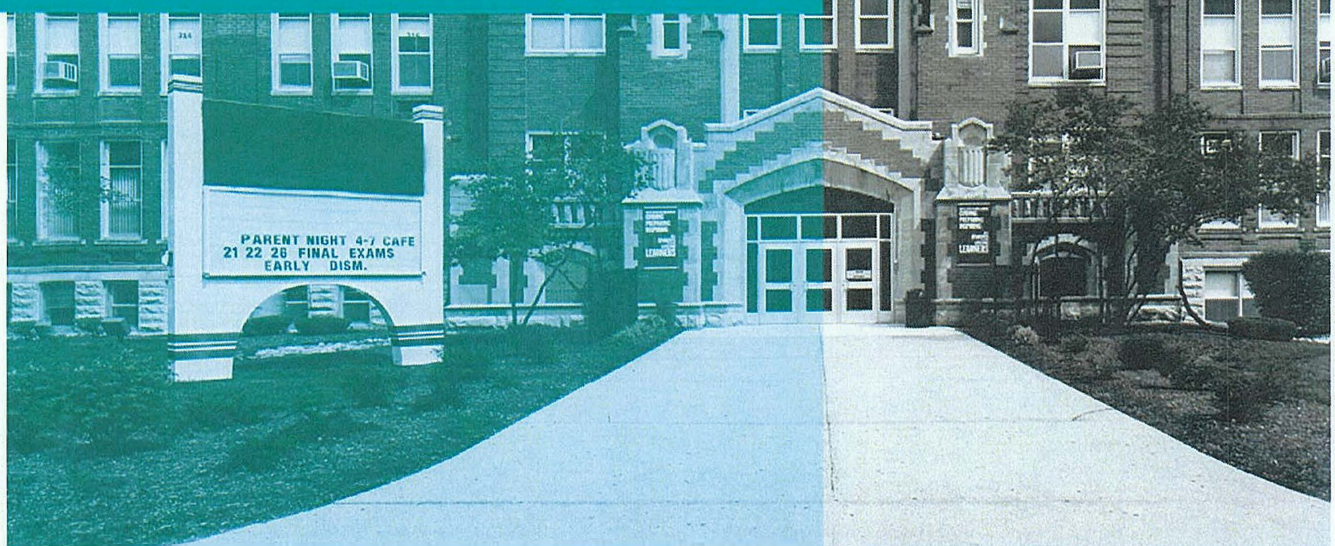
Section 4

Innovative Practices for Elementary Science Instruction

INNOVATIVE PRACTICES FOR ELEMENTARY SCIENCE INSTRUCTION

Prepared for Mountain View Whisman School District

August 2018



In the following report, Hanover Research reviews best practices for innovative science instruction at the elementary school level, and discusses alignment to the Next Generation Science Standards.

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EXECUTIVE SUMMARY

INTRODUCTION

In this report, Hanover Research reviews instructional strategies, classroom resources, and creative spaces to support innovative science programming at the elementary level, as well as the implementation of the Next Generation Science Standards (NGSS). This research will support Mountain View Whisman School District in revising its science program to align with 21st century learning standards and the NGSS as adopted by the California Department of Education. This report includes the following sections:

- **Section I** reviews effective instructional strategies for elementary science instruction, including the use of real-world problems and hands-on activities, before discussing innovative approaches such as STEAM Labs and Makerspaces.
- **Section II** reviews best practices for revising the elementary science curriculum to align with the NGSS.

RECOMMENDATIONS

Mountain View Whisman School District should implement instructional strategies that incorporate inquiry-based learning and support for student discussion.

District administrators should review innovative classroom practices or models to determine feasibility in the district, and may gather additional insight from other districts regarding the design, planning, funding, and outcomes of their STEAM Labs or other programs.

The district may evaluate instructional units and lesson plans for alignment with the NGSS using the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric for science.

KEY FINDINGS

- **Schools should incorporate hands-on science activities into the curriculum beginning in Kindergarten.** Hands-on activities may be particularly beneficial for students in the elementary grades who are still developing the abstract thinking skills needed to comprehend scientific concepts. Hands-on activities in the elementary grades may include engineering and design activities or integration of activities from other content areas such as the arts.
- **Effective science instruction also requires support for discussion among students.** Several of the essential aspects of science and engineering instruction identified by the National Research Council, such as communicating questions and arguing from evidence, require communication among students. The National Research Council recommends that science instruction provide students with opportunities to participate in classroom discussions to develop familiarity with the norms and distinct language of scientific discourse and to gain proficiency in evidence-based argumentation.

- **Many districts across the country are beginning to consider innovative changes to science instruction and traditional classroom learning, which includes the increasing popularity of Makerspacers, STEAM Labs, and augmented reality.** Makerspaces, FabLabs, and STEAM Labs are commonly designed in unused classrooms, include elements of a science lab, computer lab, woodshop, and/or art room, and may use 3D printers, building materials, invention kits, and laser cutters to allow students to engage in creative team-based projects. Similarly, augmented reality engages students in new and interactive ways, such as scavenger hunts, augmented field trips, or virtual expeditions, and only requires a smartphone or tablet and specific apps.
- **The NGSS embrace a shift towards investigating scientific phenomena over abstract lessons on scientific topics.** Phenomena-focused instruction enables students to apply knowledge to new contexts more effectively than abstract instruction and encourages students to take responsibility for their learning. Teachers should identify one or two phenomena that are relevant to their students to serve as anchor phenomena for each instructional unit.
- **The NGSS require teachers to integrate three dimensions of science education into instructional units: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas.** Schools can ensure that instruction addresses all three dimensions by bundling performance expectations for each dimension of the NGSS into each instructional unit. Schools may also need to provide additional professional development, such as lesson-planning templates, to support teachers in integrating engineering practices into science instruction.
- **Schools can integrate engineering practices into instruction by adopting integrated science technology, engineering, and mathematics (STEM) curricula.** Integrated STEM connects concepts and practices across the STEM disciplines within a single instructional unit. Effective STEM programs rely on inquiry-based instructional strategies such as problem-based learning and promote student engagement through learning activities that are authentic and relevant to students' interests. Problems should incorporate a real-world context, although contrived problems can be effective in situations where real-world problems would be too complex for elementary-grades students.

SECTION I: BEST PRACTICES AND INNOVATIVE STRATEGIES FOR INSTRUCTION

In this section, Hanover Research discusses instructional best practices for science classrooms at the elementary school level, before reviewing innovative strategies for redesigning science classrooms and enhancing student engagement. This section begins with an overview of effective instructional strategies for science in the elementary grades before discussing instructional strategies to promote STEM. This section also discusses instruction focused on scientific phenomena, before examining the innovative practices of Makerspaces, STEAM Labs, and augmented reality.

OVERVIEW OF EFFECTIVE INSTRUCTION

In order to support student success in the 21st Century, the National Science Teachers Association (NSTA) states that "the elementary science program must provide opportunities for students to develop understandings and skills necessary to function productively as problem-solvers in a scientific and technological world." The NSTA states that students learn best when:

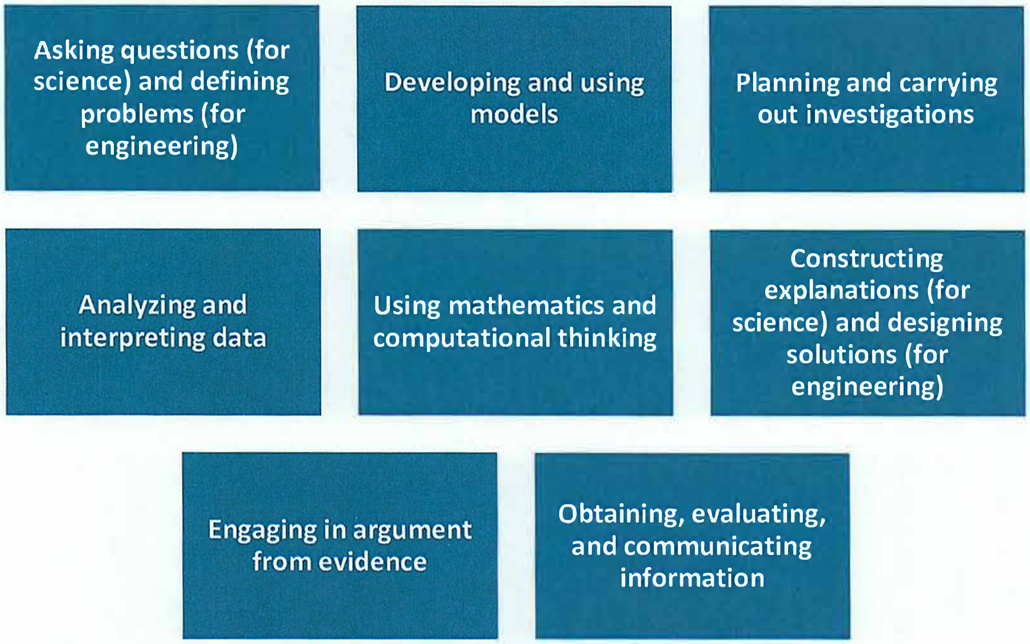
- They are involved in first-hand exploration and investigation and inquiry/process skills are nurtured;
- Instruction builds directly on the student's conceptual framework;
- Content is organized on the basis of broad conceptual themes common to all science disciplines; and
- Mathematics and communication skills are an integral part of science instruction.[1]

More specifically, the National Research Council (NRC) discusses effective science instruction and outlines a range of teacher-directed and student-directed instructional activities to develop students' knowledge of scientific concepts and participation in scientific practices.[2] The NRC identifies eight essential instructional activities for science and engineering, listed in Figure 1.1.

[1] Bulleted points taken verbatim from: "NSTA Position Statement: Elementary School Science." National Science Teachers Association. http://www.nsta.org/about/positions/elementary.aspx

[2] "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas: Dimension 1, Scientific and Engineering Practices." National Research Council, 2012. pp. 253–254. https://www.nap.edu/read/13165/chapter/7

Figure 1.1: Essential Instructional Activities for Science and Engineering



Source: National Research Council[3]

Notably, several of the essential instructional activities listed in Figure 1.1 require students to communicate ideas or questions with one another. A 2007 consensus report on science instruction in Grades K-8 produced by the National Research Council (NRC) recommends that teachers "provide opportunities for interaction in the classroom, where students carry out investigations and talk and write about their observations of phenomena, their emerging understanding of scientific ideas, and ways to test them."[4] In particular, students need to participate in classroom discussions to develop familiarity with the norms and distinct language of scientific discourse and to gain proficiency in evidence-based argumentation.[5] Teachers should use a variety of discussion formats to promote evidence-based reasoning and depth of understanding.[6] Figure 1.2 highlights benefits of different discussion formats commonly used in elementary school classrooms.

Figure 1.2: Classroom Discussion Formats

FORMAT	DESCRIPTION	BENEFITS
Whole-Group	All students in the class discuss a shared problem or concept with teacher guidance to support students and ensure appropriate behavior	Promotes intellectual engagement and depth of understanding

[3] Chart contents taken directly from: Ibid., p. 41.
[4] Duschl, R.A., H.A. Schweingruber, and A.W. Shouse. "Taking Science to School: Learning and Teaching Science in Grades K-8." National Research Council, 2007. p. 6. https://www.nap.edu/read/11625/chapter/4
[5] Ibid., p. 187.
[6] Michaels, S. and C. O'Connor. "Talk Science Primer." The Inquiry Project | Technical Education Research Centers, 2012. p. 1. https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

Format	Description	Benefit
Small-Group	Students work in groups of two to four to develop shared solutions to a problem, with the teacher circulating to monitor students and provide support as needed, before reconvening for whole-class discussion	Students may be more comfortable sharing ideas with a small group than the entire class; opportunities to refine ideas in small-group discussion enhance the quality of whole-group discussion
Partner Talk	Students briefly discuss a question with a partner before providing more formal answers in a whole-group discussion	Maximizes participation and may be especially beneficial for shy students or English Learners

Source: Technical Education Research Centers[7]

INSTRUCTIONAL STRATEGIES TO SUPPORT STEM

Effective elementary STEM instruction is student-centered and engages students through inquiry-based approaches such as real-world problem-solving, problem-based learning, and hands-on activities. [8] Within an inquiry, student-centered approach, teachers act as classroom facilitators.[9] A 2015 study of science achievement across countries using data from the Programmed for International Student Assessment finds a significant correlation between inquiry-based teaching and science achievement, with the highest level of achievement occurring when students "conduct activities and draw conclusions from data."[10] Teachers should plan projects that lead to STEM proficiency, engage student interest and motivation, facilitate the problem-solving process, and prompt questions among students.[11]

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[7] Chart contents adapted from: Ibid., pp. 7–8.

[8] [1] Chiu, A., Aaron Price, and Elsie Ovrahim. "Supporting Elementary and Middle School STEM Education at the Whole-School Level: A Review of the Literature." Chicago Museum of Science and Industry, Paper Presented at NARST 2015 Annual Conference, April 2015. p. 8. https://www.msichicago.org/fileadmin/assets/educators/science_leadership_initiative/SLI_Lit_Review.pdf [2] "Maryland State STEM Standards of Practice Framework Grades K - 5." Maryland State Department of Education, April 2012. pp. 4, 7. http://mdk12.msde.maryland.gov/instruction/academies/MDSTEM_Framework_GradesK-5.pdf

[9] "Maryland State STEM Standards of Practice Framework Grades K - 5," Op. cit., p. 4.

[10] Jiang, F. and W.F. McComas. "The Effects of Inquiry Teaching on Student Science Achievement and Attitudes: Evidence from Propensity Score Analysis of PISA Data." *International Journal of Science Education*, 37:3, 2015. sec. Abstract. https://eric.ed.gov/?id=EJ1051069

[11] "Maryland State STEM Standards of Practice Framework Grades K - 5," Op. cit., p. 7.

Inquiry-based STEM instruction incorporates problem-based learning, which is an instructional approach that "encourages students to be active learners by engaging them in loosely structured problems that resemble situations they might encounter in their lives and for which multiple solutions are possible." [12] Features of effective problem-based instruction include:[13]

- Student-centeredness;
- Small group work;
- Teachers as facilitators or guides;
- Problems as both the focus and stimulus for learning; and
- Acquisition of new information through self-directed learning.

Inquiry-based STEM instruction includes:

- ✓ *Problem-based learning*
- ✓ *Project-based learning*
- ✓ *Real-world examples*
- ✓ *Hands-on learning*

Although research supports the use of inquiry-based science instruction at the elementary school level, elementary school teachers may face classroom management challenges when implementing inquiry-based instruction.[14] A 2010 article published in the *Journal of Science Teacher Education* identifies the classroom management needs for inquiry-based science learning shown in Figure 1.3.

Figure 1.3: Classroom Management Needs for Inquiry-Based Science Instruction

Management Area	Need
Students	Teachers need to scaffold instructional support so that students have enough autonomy to engage with scientific ideas while providing enough structure to ensure learning.
Instructional Materials	Teachers need to manage instructional materials, including technology resources, to scaffold student learning and ensure that inquiry activities align with curriculum goals.
Tasks	Teachers need to assign authentic tasks and clarify the learning goal and purpose of tasks for students.
Science Ideas	Teachers need to sustain the coherence of science ideas across lessons and instructional units by eliciting prior knowledge and continually assessing students' thinking and ideas.
Classroom Community	Teachers need to create an engaging learning environment which encourages students to share ideas and learn from peers.

Source: *Journal of Science Teacher Education*[15]

[12] *STEM Integration in K-12 Education*, Op. cit., p. 44.
[13] Bullet points quoted verbatim with modification from: Ibid.
[14] Harris, C.J. and D.L. Rooks. "Managing Inquiry-Based Science: Challenges in Enacting Complex Science Instruction in Elementary and Middle School Classrooms." *Journal of Science Teacher Education*, 21:2, March 31, 2010. p. 230. http://static.nsta.org/connections/middleschool/201107harris.pdf
[15] Chart contents adapted from: Ibid., pp. 230–236.

REAL-WORLD PROBLEMS

In elementary STEM instruction, problem-based learning should include a real-world focus. Real-world problem-solving instruction often requires the integration of multiple disciplines, thus fulfilling the best practices for an integrated STEM curriculum.[16] The U.S. Department of Education notes that challenging students to apply their STEM knowledge to solve real-world problems "provides them with the opportunity to understand the relevance of STEM to their lives and to see the value of STEM in addressing issues that are important to their communities."[17]

However, the NRC notes that while problem-solving often aims for authentic opportunities, students also learn from contrived problems meant to support student learning, especially when authentic problems may be too complex. Teachers should work to balance authentic and contrived problem-solving opportunities for providing STEM instruction.[18] Figure 1.4 below discusses some examples of real-world problem-solving activities appropriate for elementary students at different grade levels. Overall, the purpose of working on real-world challenges is to teach STEM content while developing students' problem-solving skills, interdisciplinary teamwork skills, and persistence.[19] Rather than taking a direct instruction approach, effective elementary STEM instruction engages students in active learning through the investigation of real-world problems with a hands-on approach.[20]

Figure 1.4: Examples of Real-World Problem-Solving

Students in Kindergarten or PreK could be asked to come up with a "why" question that they work together on with the teacher to solve as co-discoverers.

Elementary students may be tasked with designing a mechanism or tool to prevent instances of spilled milk during mealtimes.

Upper grade students can be engaged in role-play as a team of engineers and scientists who are working together within a fictional story line to recommend a solution suited to the local environment.

Source: U.S. Department of Education[21]

[16] *STEM Integration in K-12 Education*, Op. cit., p. 98.
[17] Tanenbaum, C. "STEM 2026: A Vision for Innovation in STEM Education." U.S. Department of Education, September 2016. p. 13. https://innovation.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf
[18] *STEM Integration in K-12 Education*, Op. cit., p. 145.
[19] Tanenbaum, Op. cit., p. 13.
[20] "Maryland State STEM Standards of Practice Framework Grades K - 5," Op. cit., p. 4.
[21] Figure contents quoted verbatim with modification from: Tanenbaum, Op. cit., p. 13.

Student Engagement in STEM

Experts emphasize the importance of creating engaging STEM learning opportunities relevant to students' interests. [22] The NRC prioritizes student engagement in STEM instruction, stating that "effective instruction capitalizes on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest."[23] Similarly, the NGSS state that incorporating student interests, experience, and enthusiasm is critical to science instruction.[24] Experts note that "there is a substantial body of research that supports the close connection between the development of concepts and skills in science and engineering and such factors as interest, engagement, motivation, persistence, and self-identity."[25] Moreover, instruction that engages students and increases their interest in STEM fields can lead students to pursue additional STEM education and STEM-related careers. As the NGSS note, "Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more."[26]

The Education Development Center (EDC) finds that "Educators must develop a toolbox of approaches that is large enough to stimulate the interest of many students and flexible enough to meet the needs of a wide variety of young people, who have a wide variety of motivations."[27] The EDC recommends the following approaches for increasing student interest and engagement in STEM instruction:[28]

- Relate science to students' daily lives;
- Employ hands-on tasks and group activities;
- Use authentic learning activities;
- Incorporate novelty and student decision-making into classroom lessons; and
- Ensure that STEM curricula focus on the most important topics in each discipline.

Experts emphasize the importance of creating engaging STEM learning opportunities relevant to students' interests.

[22] "Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics." National Research Council, 2011. pp. 18–19. http://www.stemreports.com/wp-content/uploads/2011/06/NRC_STEM_2.pdf

[23] Ibid.

[24] "Next Generation Science Standards: For States, by States." National Academy of Sciences, 2013. p. xviii. https://download.nap.edu/cart/download.cgi?record_id=18290

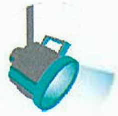
[25] Ibid.

[26] Ibid.

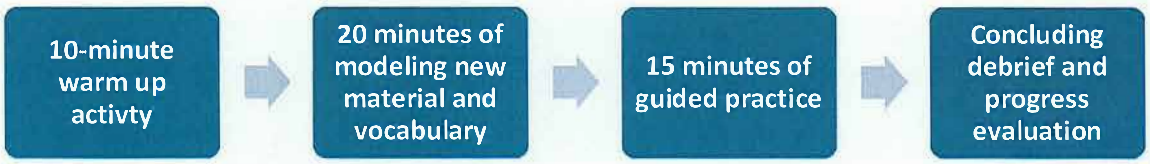
[27] "Improving STEM Curriculum and Instruction: Engaging Students and Raising Standards." Education Development Center. p. 5. http://successfulstemeducation.org/sites/successfulstemeducation.org/files/STEM%20Curriculum%20Instruction_FINAL.pdf

[28] Bullet points quoted verbatim with modification from: Ibid.

SPOTLIGHT – SAN DIEGO UNIFIED SCHOOL DISTRICT



San Diego Unified School District in California provides an example of a school district that uses arts integration to support student engagement in STEM. The district supplements standard science instruction with integrated science, technology, engineering, arts, and mathematics (STEAM) through the San Diego Teaching Artist Project (TAP) in its high-poverty schools. Each STEAM lesson follows the sequence shown below:[29]



Source: *Journal of Learning Through the Arts*[30]

STEAM lessons in San Diego Unified School District align with and expand on the district's standard science curriculum, the Full Option Science System (FOSS). Teachers use dance and music activities to help students visualize scientific concepts and review content from previous science instruction.[31] Figure 1.5 shows the science and dance standards addressed by a sample of STEAM lessons, along with links to detailed lesson plans.

Figure 1.5: Sample STEAM Lessons

TOPIC	SCIENCE STANDARDS	DANCE STANDARDS
Grade 3 – Forms of Energy	▪ Students know that sources of stored energy take many forms, such as food, fuel, and batteries. ▪ Students know machines and living things convert stored energy to motion and heat.	▪ Perform short movement problems, emphasizing the element of force/energy (e.g., swing, melt, explode, quiver).
Grade 4 – Ecosystems	▪ Students know plants are the primary source of matter and energy entering most food chains. ▪ Students know producers and consumers (herbivores, carnivores, omnivores, and decomposers) are related in food chains and food webs and may compete with each other for resources in the ecosystem.	▪ Demonstrate mental concentration and physical control in performing dance skills. ▪ Create, develop, and memorize set movement patterns and sequences.

[29] Graham, N.J. and L. Brouillette. "Using Arts Integration to Make Science Learning Memorable in the Upper Elementary Grades: A Quasi-Experimental Study." *Journal for Learning through the Arts*, 12:1, 2016. p. 5. https://eric.ed.gov/?q=ngss+elementary&ft=on&ff1=dtySince_2014&id=EJ1125147
[30] Chart contents adapted from: Ibid., p. 6.
[31] Ibid., pp. 4–5.

Topic	Science Standards	Dance Standards
Grade 5 – The Circulatory System	▪ Students know many multicellular organisms have specialized structures to support the transport of materials. ▪ Students know how blood circulates through the heart chambers, lungs, and body and how carbon dioxide (CO_2) and oxygen (O_2) are exchanged in the lungs and tissues.	▪ Incorporate the principles of variety, contrast, and unity with dance studies. ▪ Create, memorize and perform complex sequences of movement with greater focus, force/energy, and intent.

Source: Teaching Artist Project[32]

A 2016 study in the *Journal of Learning Through the Arts* examines the impact of the San Diego TAP lessons on student achievement by comparing science test scores for students receiving STEAM lessons to a control group of students receiving San Diego Unified School District's standard science curriculum.[33] The study finds a moderate improvement in students' science achievement after participating in STEAM lessons, suggesting that integrating hands-on arts activities to create concrete representations of scientific concepts can benefit students in the elementary grades.[34]

INVESTIGATING SCIENTIFIC PHENOMENA

The NGSS embrace a shift in instructional focus that deemphasizes abstract knowledge in favor of understanding phenomena, defined as "observable events that occur in the universe and that we can use our science knowledge to explain or predict." According to the NGSS, phenomena-focused instruction enables students to apply knowledge to new contexts more effectively than abstract instruction and encourages students to take responsibility for their learning.[35] The NSTA recommends that teachers use investigations of phenomena to develop student understanding of scientific concepts across disciplinary contexts.[36]

The NGSS recommends that teachers focus each instructional unit on one or two anchor phenomena, with additional investigative and everyday phenomena to build student interest and connect learning across content areas.[37] The NGSS curriculum framework adopted by the California Department of Education provides examples of anchor phenomena for each instructional unit, but recommends that individual school districts select anchor phenomena

[32] Chart contents accessed through: "Teaching Artist Project." University of California, Irvine. http://sites.uci.edu/teachingartistproject/
[33] Graham and Brouillette, Op. cit., p. 10.
[34] Ibid., p. 12.
[35] "Using Phenomena in NGSS-Designed Lessons and Units." Achieve and Next Generation Science Standards, September 2016. p. 1. http://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf
[36] "NSTA Position Statement: Transitioning from Scientific Inquiry to Three-Dimensional Teaching and Learning." National Science Teachers Association, February 2018. http://www.nsta.org/about/positions/3d.aspx
[37] "Using Phenomena in NGSS-Designed Lessons and Units," Op. cit., p. 2.

because "phenomena need to be relevant to the students that live in each community and should flow in an authentic manner."[38] The Institute for Science and Mathematics Education at the University of Washington identifies the criteria for effective anchor phenomena shown in Figure 1.6.

Figure 1.6: Criteria for Effective Anchor Phenomena

- A good anchor builds upon every day or family experiences: who students are, what they do, where they came from. It is important that it is compelling to students from non-dominant communities (e.g., English language learners, students from cultural groups underrepresented in STEM, etc.).
- A good anchor will require students to develop understanding of and apply multiple performance expectations while also engaging in related acts of mathematics, reading, writing, and communication.
- A good anchor is too complex for students to explain or design a solution for after a single lesson.
    - The explanation is just beyond the reach of what students can figure out without instruction.
    - Searching online will not yield a quick answer for students to copy.
- A good anchor is observable to students. "Observable" can be with the aid of scientific procedures (e.g., in the lab) or technological devices to see things at very large and very small scales (telescopes, microscopes), video presentations, demonstrations, or surface patterns in data.
- A good anchor can be a case (pine beetle infestation, building a solution to a problem), something that is puzzling (why isn't rainwater salty?), or a wonderment (how did the solar system form?).
- A good anchor has relevant data, images, and text to engage students in the range of ideas students need to understand. It should allow them to use a broad sequence of science and engineering practices to learn science through first-hand or second-hand investigations.
- A good anchor has an audience or stakeholder community that cares about the findings or products.

Source: Institute for Science and Mathematics Education at the University of Washington[39]

Hands-On Activities

Students' investigation of phenomena should include hands-on activities. The American Chemical Society recommends that students begin participating in hands-on activities in Kindergarten.[40] Research conducted across grade levels finds a significant impact of hands-on science instruction on student achievement. Hands-on activities may be particularly beneficial for students in the elementary grades, who are often still developing the capacity for abstract thought. These students benefit from concrete representations of scientific phenomena, such as the Earth's axis of rotation.[41]

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[38] "2016 Science Framework - Curriculum Frameworks Chapter 3: Kindergarten Through Grade 2," Op. cit., p. 4.

[39] Chart contents taken directly from: Penuel, W.R. and P. Bell. "Qualities of a Good Anchor Phenomenon for a Coherent Sequence of Science Lessons." Institute for Science and Mathematics Education, University of Washington, March 2016. http://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-28-Qualities-of-Anchor-Phenomena.pdf

[40] "Importance of Hands-On Laboratory Science." American Chemical Society, 2017. https://www.acs.org/content/dam/acsorg/policy/publicpolicies/education/computersimulations/hands-on-science.pdf

[41] Graham and Brouillette, Op. cit., p. 2.

In the elementary grades, schools can incorporate hands-on activities into instruction by having students solve engineering projects in class.[42] For example, the National Research Council provides sample engineering and design activities recommended for the elementary grades, including:

- Constructing a bridge from paper and tape and testing it until failure occurs;
- Designing a traffic pattern for the school parking lot; and
- Designing a layout for planting a school garden box.[43]

Schools can also use STEM integration to increase opportunities for hands-on learning. The U.S. Department of Education recommends using hands-on investigations to give students the opportunity to engage in "some of the core values and practices of science and engineering in practice; namely, searching for uncertainty, recognizing ambiguity, and learning from failure."[44] Schools should create opportunities for students to engage in STEM discovery, play, and risk through creative activities, such as science fairs or informal learning settings (e.g., science museum trips). The U.S. Department of Education notes that "Intentional play activities can support this type of learning experience by providing students with time to explore their uncertainties, construct knowledge from experience, and strengthen relationships."[45] Other opportunities for hands-on STEM learning include using physical models and structures and engaging activities.[46]

INNOVATIVE CLASSROOM SPACES

Beyond changes to curriculum structure and instructional practices, elementary schools can also redesign classroom spaces to enhance student engagement and learning in science. According to a position paper by the U.S. Department of Education:

> The nation also can begin to draw on and learn lessons from innovative uses of learning spaces and technologies that offer students and educators the flexibility to move tools, collaborate around tools, and build or use physical, simulated, and virtual environments that adapt to the learning activity of the moment and apply [universal design for learning] principles to promote accessibility and inclusion.[47]

Below, Hanover outlines innovative strategies for creating engaging science instruction that align with 21st century technology.

[42] "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas: Dimension 1, Scientific and Engineering Practices," Op. cit., p. 71.
[43] Chart contents taken directly from: Ibid.
[44] Tanenbaum, Op. cit., p. 10.
[45] Ibid.
[46] Ibid.
[47] "STEM 2026: A Vision for Innovation in STEM Education." U.S. Department of Education. September 2016. P. 37. https://innovation.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf

MAKERSPACES, FABLABS, AND STEAM LABS

Makerspaces have become increasingly popular in schools, as districts seek to engage students and provide new and meaningful learning experiences. According to one Edutopia article, "Makerspaces provide hands-on, creative ways to encourage students to design, experiment, build, and invent as they deeply engage in science, engineering, and tinkering."[48] Makespaces may contain elements of a science lab, woodshop, computer lab, or art room, and should include diverse activity options to allow for student exploration and creativity. When planning for the installation of a Makerspace, districts should consider several questions, including required tools, leadership and oversight, and funding.

Figure 1.7: Makerspace Planning Questions and Considerations

PLANNING QUESTIONS	CONSIDERATIONS
What range of "subjects" will be taught in the space? What types of activities and projects could be done there?	Makerspace design should be led by a science, math, technology, and/or art teacher.
Which tools are most needed? Will digital fabrication tools such as CNC routers, laser cutters, or 3D printers be included? Which materials will be used?	Many types of equipment have special requirements to ensure a safe work space, such as ventilation.
Who are the kids that will be using the space? Will others use the space as well? Who is staffing and managing the space?	The space should be functional for a range of ages, and should also support after-school programs, electives, or even parent groups.
When will the space be used?	
Where in the school or on the campus would be ideal? What considerations are important?	The space should be easily accessible for cars, near outdoor work areas, and where noise won't disturb other students.
How will it be built? Is a new or separate structure needed, and if so, what type? What is the budget?	

Source: Edutopia[49]

Helpful resources may include ***The Makerspace Playbook*** and ***Invent to Learn***. It should also be noted that schools or districts may seek financial or resource support through the community, as "often, local business and tech companies are more than happy to contribute to what they consider the engagement and training of future employees."[50]

[48] Cooper, Jennifer. "Designing a School Makerspace." Edutopia. September 30, 2013. https://www.edutopia.org/blog/designing-a-school-makerspace-jennifer-cooper
[49] Ibid.
[50] Hertz, Mary Beth. "Creating Makerspaces in Schools." Edutopia. Nov 6, 2012. https://www.edutopia.org/blog/creating-makerspaces-in-schools-mary-beth-hertz

Spotlight: Montour Elementary School

Montour Elementary School, a K-4 school in Pennsylvania, was recently profiled in *THE Journal* for opening the first "Brick Makerspace." This Makerspace features a STEAM lab created in partnership with Lego Education and Carnegie Mellon University. According to school leaders, the goal of the new Makerspace was to create "a room that would inspire students to become architects, engineers, designers, makers, and use problem-solving and critical thinking skills. We wanted a room that made students curious to learn and discover amazing things along the way."[51]

The Makerspace is themed around Legos, and activities range from "brick building to 3D printing to car racing to stop-motion animation to an interactive mixed reality system that lets students build structures and test their physical properties." The room features several tools, including Lego Education's WeDo2.0, Lego MINDSTORMS Education EV3, and Lego Education Simple and Powered Machines.

The school also includes a Minecraft Education Lab (in partnership with Microsoft Education), a Google Lab, a STEAM Lab, and an Upcycling Room, and is finishing construction on an MIT Fab Lab.

Makerspaces may also be referred to as "Fablabs," which allow students to use cutting edge technology to create projects. For example, a 2013 Forbes article profiled Bullis Charter Schools in Silicon Valley, where elementary students engage with the school's Fablab. The principal explains that "instead of using cardboard and paper to create models, [students] can test their prototypes in 3-D simulations using the same innovative tools that are being used in the business world."[52]

Students use the Fablab in two stages. First, the school provides workshops to focus on a specific skill, such as soldering, 3-D modeling, laser cutting, or visual programming. Once students have acquired the skill, the second stage uses project-based learning to allow students to work in teams and generate solutions to real-world problems. The school believes that learning through the Fablab will not only produce students with specific scientific or technology-related skills, but who also have the ability to communicate, collaborate, and work on a team.[53]

More commonly, however, districts refer to these spaces as STEAM Labs. These labs feature similar equipment to Makerspaces or Fablabs, such as 3D printers and building materials, and allow students in the school to rotate through the lab on a weekly basis or frequently throughout the year. School districts across the country publish information on the design and functions of STEAM labs, such as Concord Public Schools in Massachusetts, which provides this **PowerPoint presentation** with sample lessons for Grades K-5 and an estimate of costs for lab materials. Similarly, Old Mill Elementary in Louisville, Kentucky, hosts a STEAM lab that posts weekly sample lessons for Grades K-3 and 4-5, located **here**. Through the use

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[51] Nagel, David. "The STEAM Powered Elementary School: Montour Opens World's First Lego-Themed Brick Makerspace." *THE Journal*. February 26, 2018. https://thejournal.com/Articles/2018/02/26/The-STEAM-Powered-Elementary-School.aspx?Page=1

[52] Hwang, Victor W. "How Does Silicon Valley Teach Its Children? With A FabLab!" *Forbes*. August 7, 2013. https://www.forbes.com/sites/victorhwang/2013/08/07/how-does-silicon-valley-teach-its-children-with-a-fablab/#4dfe24961d68

[53] Ibid.

of 3D printing, teachers at this school developed a project that allowed Grade 4 students to build a prosthetic arm for one of their classmates. The process included researching prosthetics, building plans, and 3D printing, and encouraged the concepts of "biomedical engineering, problem solving... empathy, and understanding."[54]

Spotlight: Ridgeway Elementary School

Ridgeway Elementary School, located in Manchester, New Jersey, recently used a $15,000 grant from their local education foundation to build a STEAM Lab that includes robots, electronics kits, and a 3D Doodler station, as well as "Lego Mindstorm, a 3D printer, puppet theater, blocks and blueprints, spiral art, pipe builders, and Madedo connectors for building with cardboard."[55]

The school built the STEAM Lab in the former computer lab, which was underutilized after the school purchased Chromebooks. The room was redesigned to feature "innovative workstations and equipment that enables students to get creative and demonstrate the scientific method through teamwork, problem solving, and abstract thinking." The most popular tools in the STEAM Lab include the robots, the 3D Doodler station, and the electronics kits. The electronics kits include Squishy Circuits and Makey Makey (discussed below).

Makey Makey is "an invention kit for the 21st century" that allows students to "turn everyday objects into touchpads and combine them with the internet."[56] The product, which can be used with elementary aged children, is designed to "help people start to think of themselves as Makers and agents of change." Makey Makey offers an Educator Guide and sample lesson plans, such as "Simple Circuits Challenge," "Makey Makey Game Controller Challenge," and "Distance, Rate and Time for Math/Science/Physics."[57] The "classic" kit retails for $49.95, or schools may purchase the "STEM Pack- Classroom Invention Literacy Kit" for $699.95.[58]

Augmented Reality

Another increasingly popular topic in school is the use of augmented reality. Augmented reality (AR), which "layers computer-generated enhancements on top of an existing reality in order to make it more meaningful through the ability to interact,"[59] enhances student engagement and provides unique learning experiences. Unlike STEAM Labs or Makerspaces, using AR in the classroom requires only a smartphone or tablet and an AR app. Given the new and ever-evolving nature of AR, there are few scholarly resources discussing the topic at the elementary level, and the majority of information is found on educational or technology websites.

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[54] Clark, Kristen. "Fourth graders create prosthetic arm for peer." *Courier Journal.* March 24, 2015. https://www.courier-journal.com/story/news/local/bullitt/2015/03/24/fourth-graders-create-prosthetic-arm-peer/70384362/

[55] "New STEAM Lab Opens at Ridgeway Elementary School." Manchester Township School District. https://www.manchestertwp.org/news/articles/~news-id/329

[56] "Mission." Makey Makey. https://makeymakey.com/pages/mission

[57] "Resources." Makey Makey. https://makeymakey.com/pages/educators#resources

[58] "Shop." Makey Makey. https://makeymakey.com/pages/featured-products

[59] "Augmented reality in the classroom." Discovery Education. August 1, 2017. http://blog.discoveryeducation.com/blog/2017/08/01/augmentedreality/

Teachers can use AR apps to create a variety of student experiences, such as digital puzzle boxes, scavenger hunts, augmented field trips, and virtual expeditions. Through Google Expeditions, for example, students can explore topics from 3D models of volcanoes to the human body.[60]

Discovery Education highlights the following AR apps that may support science instruction:[61]

- **Quiver Education**
- **EON Experience**
- **DAQRI Anatomy 4D**
- **Science AR**
- **Amazing Space Journey**

Another common resource is **HP Reveal** (formerly Aurasma). Further, Metaverse AR maintains a **Google document** where teachers share projects they have created through the app that can be used by other educators.

6060 Crews, Jeff. "Five ways teachers can use – and create – augmented reality experiences." EdSurge. January 22, 2018. https://www.edsurge.com/news/2018-01-22-five-ways-teachers-can-use-and-create-augmented-reality-experiences

61 Ibid.

SECTION II: ALIGNING CURRICULUM TO THE NGSS

In this section, Hanover Research reviews best practices for aligning science curricula to the NGSS in Grades K-5. This section begins with a discussion of curriculum innovations in the NGSS before discussing resources schools and districts can use to evaluate the alignment of existing or proposed curricular materials to the NGSS. This section concludes with a discussion of strategies to integrate the three dimensions of science instruction within the NGSS (Scientific and Engineering Practices, Cross-Cutting Concepts, and Disciplinary Core Ideas) into bundled units of instruction, including integrated science, technology, engineering, and math (STEM) programs.

CURRICULUM INNOVATIONS IN THE NGSS

The California State Board of Education adopted a curriculum framework aligned with the NGSS in 2016.[62] This framework presents instructional units for Grades K-2 and Grades 3-5 and is available here.[63] The California Department of Education is also developing a new science assessment, the California Science Test (CAST), which aligns with the NGSS.[64]

The NGSS embrace five curricular innovations, summarized in Figure 2.1 2.1. In addition, the NGSS "calls for more student-centered learning that enables students to think on their own, problem solve, communicate, and collaborate."[65] However, the NGSS do not mandate the adoption of a specific curriculum or instructional materials.[66]

[62] "Curriculum Frameworks - Science." California Department of Education. https://www.cde.ca.gov/ci/sc/cf/

[63] "2016 Science Framework - Curriculum Frameworks." California Department of Education, February 2017. https://www.cde.ca.gov/ci/sc/cf/scifwprepubversion.asp

[64] "California Science Test - California Assessment of Student Performance and Progress (CAASPP) System." California Department of Education. https://www.cde.ca.gov/ta/tg/ca/caasppscience.asp

[65] "NGSS Fact Sheet." Next Generation Science Standards, 2016. p. 1. http://www.nextgenscience.org/sites/default/files/resource/files/NGSSFactSheet2016revised.pdf

[66] Ibid., p. 2.

Figure 2.1: Curriculum Innovations for the NGSS

Three Dimensional Learning

- **There are three equally important, distinct dimensions to learning science included in the NGSS: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The NGSS connect all three dimensions. To prepare students for success in college and 21st century careers, the NGSS also connect scientific principles to real-world situations, allowing for more engaging and relevant instruction to explore complicated topics.**

All Three Dimensions Build on Coherent Learning Progressions

- **The NGSS provide students with continued opportunities to engage in and develop a deeper understanding of each of the three dimensions of science. Building on the knowledge and skills gained from each grade—from elementary through high school—students have multiple opportunities to revisit and expand their understanding of all three dimensions by the end of high school.**

Students Engage with Phenomena and Design Solutions

- **In instructional systems aligned to the NGSS, the goal of instruction is for students to be able to explain real-world phenomena and to design solutions using their understanding of the Disciplinary Core Ideas. Students can achieve this goal by engaging in the Science and Engineering Practices and applying the Crosscutting Concepts.**

Engineering and the Nature of Science is Integrated into Science

- **Some unique aspects of engineering (e.g., identifying problems) are incorporated throughout the NGSS. In addition, unique aspects of the nature of science (e.g., how theories are developed) are also included throughout the NGSS as practices and crosscutting concepts.**

Sciences is Connected to Math and Literacy

- **The NGSS not only provide for coherence in science instruction and learning, but the standards also connect science with mathematics and English Language Arts. This meaningful and substantive overlapping of skills and knowledge affords all students equitable access to the learning standards.**

Source: Next Generation Science Standards[67]

Districts can use the NGSS curriculum framework developed by the California Department of Education to guide the structure and sequencing of the science curriculum. However, the California Department of Education recommends that school districts adapt these materials to reflect locally occurring scientific phenomena, rather than adopting them without alteration.[68] For example, schools located in the desert could have students track the number of days with a high temperature above 95 degrees for an instructional unit on weather patterns, whereas schools located in coastal areas could track the number of days with fog.[69]

[67] Chart contents taken directly from: Ibid.
[68] "2016 Science Framework - Curriculum Frameworks Chapter 3: Kindergarten Through Grade 2." California Department of Education, February 2017. p. 4. Downloaded from: https://www.cde.ca.gov/ci/sc/cf/scifwprepubversion.asp
[69] Ibid., p. 24.

EVALUATING INSTRUCTIONAL MATERIALS

Empirical research on the outcomes of specific curricula or instructional programs for elementary science is highly limited. A 2012 review of the available research by the Best Evidence Encyclopedia (BEE) identifies only 17 studies that meet the BEE's review criteria.[70] Based on its review of these studies, the BEE concludes that the evidence base is stronger for instructional programs that emphasize professional development for teachers than for programs that emphasize science kits.[71] Figure 2.2 briefly summarizes elementary science programs reviewed by the What Works Clearinghouse (WWC), and includes hyperlinks to the WWC's full intervention reports for these programs.

Figure 2.2: Elementary Science Programs Reviewed by the WWC

PROGRAM	GRADE LEVELS REVIEWED	DESCRIPTION	EFFECTIVENESS RATING
Great Explorations in Math and Science® (GEMS®) Space Science Sequence	3-5	Science curriculum sequence focused on space	Potentially positive effects on general science achievement
Technology-Enhanced Elementary and Middle School Science	3-4	Science curriculum that uses technology to support inquiry-based investigations of scientific phenomena	Potentially positive effects on general science achievement

Source: What Works Clearinghouse[72]

Although empirical research on the effectiveness of specific instructional materials is limited, schools can review instructional materials for alignment with the NGSS. The NSTA recommends that elementary schools form teams of two to five teachers to review their existing science curricula for alignment with the NGSS using the process shown in Figure 2.3. This process allows implementation teams to identify additional resources, such as professional development or curricular materials, needed to support the NGSS.[73]

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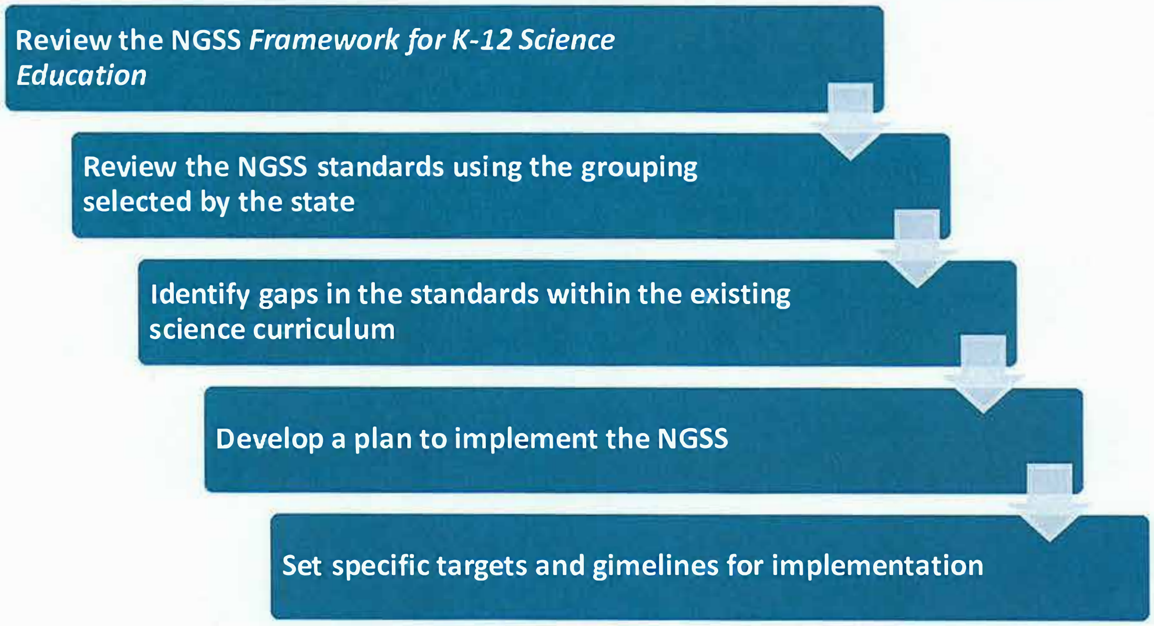
[70] Slavin, R.E. et al. "Experimental Evaluations of Elementary Science Programs: A Best-Evidence Synthesis." Best Evidence Encyclopedia, 2012. p. 8. http://www.bestevidence.org/word/elem_science_Jun_13_2012.pdf

[71] Ibid., pp. 20–22.

[72] Chart contents accessed through "Search Results: Science, Grades PK-5." What Works Clearinghouse. https://ies.ed.gov/ncee/wwc/FWW/Results?filters=,Science&customFilters=PK,K,1,2,3,4,5,

[73] "Planning an NGSS Curriculum." National Science Teachers Association, July 26, 2018. http://ngss.nsta.org/planning-an-ngss-curriculum.aspx

Figure 2.3: Suggested Process for Aligning Existing Science Curricula to the NGSS



Source: National Science Teachers Association[74]

When developing new lesson plans or instructional units, the NSTA recommends that schools use a **backward design process**. In the backward design process, teachers begin by selecting a performance expectation within the NGSS and design instructional activities which support students in reaching the expectation from a baseline knowledge level. Teachers should identify scientific phenomena that students can investigate to master the performance expectation, and then identify crosscutting concepts related to the target phenomena.[75] The NSTA endorses the BSCS 5E Instructional model, which recommends that each instructional unit address the phases listed in Figure 2.4.

Figure 2.4: BSCS 5E Instructional Model

PHASE	SUMMARY
Engagement	The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.

[74] Chart contents adapted from: Ibid.
[75] "Designing Units and Lessons." National Science Teachers Association, July 27, 2018. http://ngss.nsta.org/designing-units-and-lessons.aspx

Phase	Summary
Explanation	The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

Source: BSCS[76]

Although the NGSS does not mandate the adoption of a specific curriculum, the developers of the NGSS do provide resources that schools can use to align their curricula with the standards, including rubrics to evaluate lesson plans and instructional units.[77] In particular, the NGSS recommends that schools use the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric to evaluate textbooks and other instructional materials.[78] A fillable pdf version of the EQuIP rubric with instructions for use is available here. The NGSS also provides a screening tool for individual lessons, available here.[79] The California Science Teachers Association has partnered with science teachers associations in three other Western states to develop more detailed guidelines for instructional materials. These guidelines, available here, emphasize the following priority features:[80]

- Instructional materials should provide equitable access to the curriculum and intellectual engagement for all students;
- Instructional materials should follow a logical progression of Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts; and
- Instructional materials should align with a classroom assessment system that includes all three dimensions of the NGSS and emphasizes application of knowledge.

[76] Chart taken directly from: Bybee, R.W. et al. "The BSCS 5E Instructional Model: Origins and Effectiveness." BSCS, June 12, 2006. p. 2. https://bscs.org/sites/default/files/_media/about/downloads/BSCS_5E_Full_Report.pdf
[77] "Home." Next Generation Science Standards, July 24, 2018. http://www.nextgenscience.org/
[78] "EQuIP Rubric for Lessons and Units: Science." Achieve and National Science Teachers Association, July 27, 2018. http://www.nextgenscience.org/sites/default/files/EQuIPRubricforSciencev3.pdf
[79] "NGSS Lesson Screener." Next Generation Science Standards, July 27, 2018. https://www.nextgenscience.org/screener
[80] Boyd, A. et al. "Priority Features of NGSS-Aligned Instructional Materials: Recommendations for Publishers, Reviewers and Educators." California Science Teachers Association, Nevada State Science Teachers Association, Oregon Science Teachers Association, and Washington Science Teachers Association, October 2017. p. 2. http://www.cascience.org/application/files/5115/1796/5779/Recommendations-NGSS-Instructional-Materials-White-Paper.pdf

INTEGRATING THREE-DIMENSIONAL LEARNING INTO THE CURRICULUM

The NGSS require teachers to integrate three dimensions of science education: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas, into instructional units.[81] Schools can ensure that instruction addresses all three dimensions by bundling performance expectations for each dimension of scientific education into individual instructional units.[82] Bundling performance expectations promotes a more cohesive instructional sequence than attempting to address each performance expectation through a separate instructional unit, and ensures that all performance expectations have been addressed by the end of the school year.[83] Figure 2.5 presents a sample of bundled performance expectations for a Kindergarten instructional unit on weather patterns included in the California Department of Education's curriculum framework for the NGSS.

Figure 2.5: Example Bundled Units of Instruction for Kindergarten

Science and Engineering Practices	Disciplinary Core Ideas	Cross-Cutting Concepts
• Asking Questions and Defining Problems • Planning and Carrying Out Investigations • Analyzing and Interpreting Data • Using Mathematics and Computational Thinking • Constructing Explanations (for science) and Designing Solutions (for engineering) • Engaging in Argument from Evidence • Obtaining, Evaluating, and Communicating Information	• Conservation of Energy and Energy Transfer • Weather and Climate • Natural Hazards • Defining and Delimiting Engineering Problems • Developing Possible Solutions	• Patterns • Cause and Effect • Energy and Matter: Flows, Cycles, and Conservation

Source: California Department of Education[84]

The developers of the NGSS provide examples of performance expectations bundled thematically and by topic for each grade level from Kindergarten to Grade 5. These examples, available here, are intended to guide curriculum developers in the process of integrating three-dimensional learning into instructional units.[85] However, the NGSS emphasizes that

[81] "NGSS Fact Sheet," Op. cit., p. 1.

[82] "Bundling the NGSS." Next Generation Science Standards, July 27, 2018. https://www.nextgenscience.org/resources/bundling-ngss

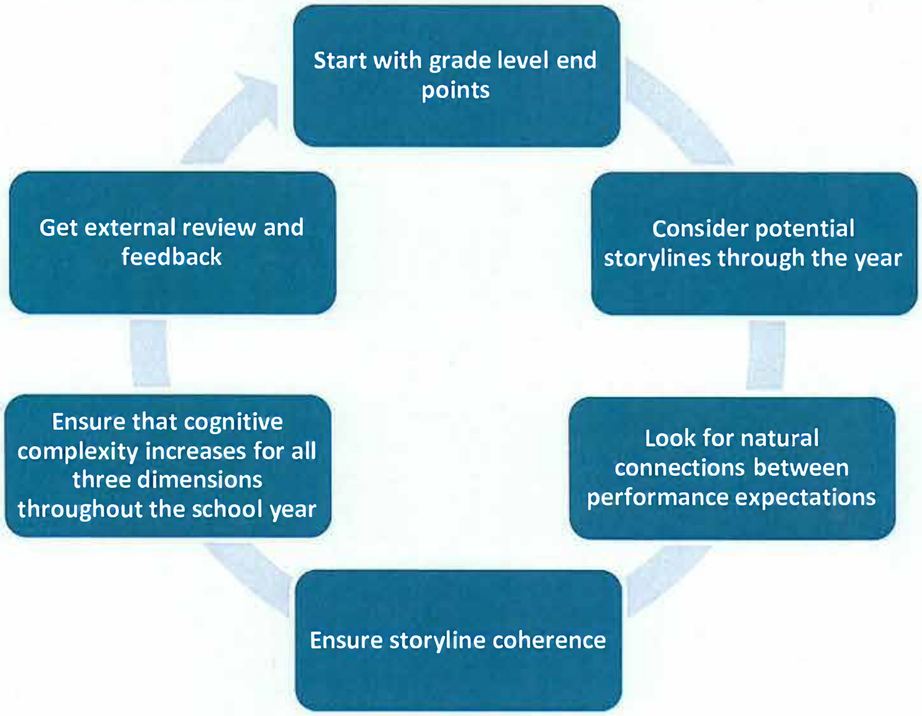
[83] "Example Bundles Guide." Next Generation Science Standards, June 2016. p. 5. https://www.nextgenscience.org/sites/default/files/Example%20Bundles%20Guide.pdf

[84] Chart taken directly from: "2016 Science Framework - Curriculum Frameworks Chapter 3: Kindergarten Through Grade 2," Op. cit., p. 22.

[85] "Bundling the NGSS," Op. cit.

curriculum designers can bundle performance expectations in multiple ways and "be creative in their approach" to bundling.[86] The developers of the NGSS recommend using an iterative process to design bundled instructional units to facilitate connections across performance expectations and to ensure that content builds logically throughout the school year.[87]

Figure 2.6: Suggested Process for Designing Bundled Instructional Units



Source: Next Generation Science Standards[88]

INTEGRATED STEM

Many schools support engineering and science instruction through integrated STEM programs. An integrated STEM curriculum combines aspects of the STEM disciplines into a lesson or unit. For example, instead of teaching science, math, or technology in three separate units, a teacher would cover aspects of all three topics together in one integrated lesson. In a comprehensive report on STEM integration, the National Research Council finds that STEM integration can connect the disciplines in three ways:[89]

- Bring together concepts from more than one discipline (e.g., mathematics and science, or science, technology, and engineering);
- Connect a concept from one subject to a practice of another, such as applying properties of geometric shapes (mathematics) to engineering design; and

[86] "Example Bundles Guide," Op. cit., p. 6.
[87] Ibid., p. 11.
[88] Chart taken with very minor alterations from: Ibid.
[89] Bullet points quoted verbatim with modification from: *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. National Research Council, 2014. p. 42. Downloaded from: https://www.nap.edu/catalog/18612/stem-integration-in-k-12-education-status-prospects-and-an

- Combine two practices, such as science inquiry (e.g., doing an experiment) and engineering design (in which data from a science experiment can be applied).

Research finds that integrated STEM instruction supports science achievement in the elementary grades. A 2013 study published in the journal *School Science and Mathematics* examines the impact of a STEM program in a sample of 70 classrooms in Grades 2-5.[90] The study finds that students who received the STEM program made significantly greater gains in science content knowledge, process skills, and conceptual understanding than students in a control group, suggesting that STEM integration can be an effective strategy to improve science achievement in the elementary grades.[91]

Based on extensive research, the NRC provides three recommendations for designing an integrated STEM curriculum, shown in Figure 2.7. These recommendations include the identification of interdisciplinary connections, support for students' content knowledge in individual subjects, and strategically providing opportunities for integration.[92]

Figure 2.7: Recommendations for Designing an Integrated STEM Curriculum

Make Integration Explicit

- Observations in a number of STEM settings show that integration across representations and materials, as well as over the arc of multi-day units, is not spontaneously made by students and therefore cannot be assumed to take place. Teachers should design integrated experiences that provide intentional and explicit support for students to build knowledge and skill both within the disciplines and across disciplines.

Support Students' Knowledge in Individual Disciplines

- Connecting ideas across disciplines is challenging when students have little or no understanding of the relevant ideas in the individual disciplines. Also, students do not always or naturally use their disciplinary knowledge in integrated contexts. Students will thus need support to elicit the relevant scientific or mathematical ideas in an engineering or technological design context, to connect those ideas productively, and to reorganize their own ideas in ways that come to reflect normative, scientific ideas and practices.

More Integration is not Necessarily Better

- The potential benefits and challenges of making connections across the STEM subjects suggest the importance of a measured, strategic approach to implementing integrated STEM education that accounts for the potential tradeoffs in cognition and learning.

Source: National Research Council[93]

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[90] Cotabish, A. et al. "The Effects of a STEM Intervention on Elementary Students' Science Knowledge and Skills." *School Science & Mathematics*, 113:5, May 2013. p. 218. Accessed via EBSCOhost

[91] Ibid., p. 224.

[92] *STEM Integration in K-12 Education*, Op. cit., p. 5.

[93] Figure contents quoted verbatim with modification from: Ibid.

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