Paper ID #26657

Designing NGSS-Aligned Lesson Plans During a Teacher Professional Development Program (Fundamental)

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Designing NGSS-Aligned Lesson Plans during a Teacher Professional Development Program (Fundamental)

1. Introduction

Rapid technological and industrial advances continue to dominate the evolution of world's economy and increasingly influence our daily lives. Even as such advances have greatly improved human living condition, a vast majority of people either lack the understanding of technology or frequently ignore it [1]. This phenomenon is more prevalent in the younger generation [2]–[4], even when it is adept at consuming various cutting-edge technologies such as gaming devices with high-performance graphics processing units (GPUs), mobile internet, smartphones, social media, etc. While post-secondary science, technology, engineering, and math (STEM) education seeks to remedy this disconnect, its reach is limited because formal education ends for many students at the secondary level [5]. To broaden the education and understanding of society about technology, it is critical to educate and prepare the younger generation about new technologies at the K-12 educational levels [1]. Such an approach can additionally lay a strong foundation in STEM disciplines for those bound for college-level education [6], [7].

Teachers serve as an essential link between their students and new information. Teachers' understanding of STEM disciplines and ability to provide practical examples of STEM in their lessons play a crucial role in student learning outcomes. Thus, a teacher with solid disciplinary education, who is practically trained and broadly informed, is pivotal for educating students [8]. While it is impractical and unfair to expect teachers to understand every innovation and advance in STEM disciplines, it is certainly feasible for them to acquire relevant experiences within their fields of expertise and interest. Such disciplinary knowledge, experiences, and interests can be shared by teachers with students and colleagues, sparking discussions, curiosity, explorations, and even criticism. Through a continual, incremental, and iterative process, additional information can be acquired and shared, and feedback can be obtained to advance teachers' learning goals for students [9], [10]. To successfully and efficiently enact such an information creation, sharing, and revision process, teachers require access to reliable sources of STEM information. Moreover, through engagement in authentic learning experiences, they gain an understanding and relevance of the newly acquired STEM information. Through a structured learning model, delineated below, they can create formal lesson plans that are grounded in the pertinent STEM information. Thus, to accomplish their learning goals for students, it is suggested that teachers engage in professional development (PD) [11] and educational enrichment opportunities for: (1) understanding basic working principles behind several latest technologies and producing clear and concise explanations and real-world examples for the same and (2) preparing and developing capacity to design and implement formal lesson plans for classroom teaching and learning activities that integrate technology. Formal lesson planning and structured execution of curriculum is essential to ensure uniform and effective learning. While students also benefit in a non-formal learning setting, it is difficult to produce standards-compliant lessons, accommodate non-formal instruction during school hours, and assess learning outcomes [12], [13]. This is even more challenging as teachers learn to create lessons aligned with the new national standards, the Next Generation Science Standards (NGSS).

The NGSS was designed by the states to ensure high-quality, contemporary K-12 science standards for remedying the limitations of prevailing teaching of science, which focuses only within teachers' content expertise and fails to illustrate the various interconnections of science to students [14]. Moreover, under the NGSS, engineering principles and practices are to be highlighted and explicitly addressed in science teaching and learning. The NGSS reimagines K-12 science to be organized using a three-dimensional (3D) learning model consisting of Disciplinary Core Ideas (DCIs), Cross Cutting Concepts (CCCs), and Science and Engineering Practices (SEPs). The DCIs are the K-12 science concepts that students must learn [15], [16]. The CCCs are pervasive across various subfields of sciences and include: patterns; cause and effect; scale, proportion, and quantity; systems and system model; energy and matter; structure and function; and stability and change. In fact, the CCCs tie together all four science domains treated in the K-12 curricula (*viz.*, physical science, life science, earth and space science, and engineering). Finally, the SEPs are eight intended and agreed upon practices that scientists and engineers utilize in their professional work. The 3D model of NGSS permits students to learn and investigate a newly presented STEM topic by exploring its central concept (DCIs) and comprehending its multi-disciplinary connections (CCCs) by engaging in inquiry and design (SEPs).

The "5E Instructional Model," consisting of the *engage*, *explore*, *explain*, *elaborate*, and *evaluate* components, is widely accepted and used in K-12 education for formulating curriculum frameworks, planning lessons, and designing PD programs [17]. More importantly, by drawing from research on how people learn, the 5E model renders a "planning tool" that effectively structures classroom learning tasks in a well-organized format and sequence to enhance student motivation, retention of information, and understanding of difficult concepts [18]. Although the 5E model was originally envisioned for and has historically promoted inquiry learning, its structured framework can be flexibly adapted to authentically address the three dimensions of the NGSS. For example, [19] suggests incorporation of classroom instructional and learning tasks such as engaging in scientific practices, formulating research questions, conducting engineering design, and refining scientific models through the phases of explanation, engagement, exploration, and elaboration, respectively. Moreover, [20] has used the 5E model to formulate and illustrate an instructional sequence that integrates the multiple dimensions of the NGSS. Specifically, [20] suggests that each phase of the 5E model can address the three dimensions of the NGSS either contextually or emphasize them explicitly. As an example, [21] has illustrated how to connect each dimension of the 3D model to the explaining phenomena phase of the 5E model. By drawing inspiration from [18], [20], [21], as shown in Section 3 below, the components of the 5E model are utilized to permit learners to experience various dimensions of the NGSS. Traditional formal learning environments rely on front-loading techniques [22], [23] to introduce new concepts wherein instruction begins with *knowing* relevant vocabulary terms, definitions, mathematical formulae, meaning of physical phenomenon, etc. With front-loading techniques, active exploration occurs only post knowledge transmission, thus framing the learners' view by and limiting their comprehension to the information and perspectives shared by teachers [22], [23]. Integration of the three dimensions of the NGSS with the use of 5E model offers a practical way to apply non-front-loaded learning as an understandable and manageable sequence, wherein the students use evidence to develop an explanation for a phenomenon through observation, critical enquiry, and analysis [20].

Flexibility offered by the 5E model and the concept elaboration provided by the 3D learning make them optimal for exploring scientific and technological concepts. Moreover, such an approach illustrates to students that the K-12 STEM concepts constitute interconnected knowledge structures, i.e., the various science disciplines are not isolated from one another. The NGSS characterizes the expectations of learning objectives and student outcomes, even as it affords the educators autonomy, agency, and flexibility to envision, create, and implement novel lessons that address requisite science concepts while also preparing students for post-secondary education [24], [25]. Furthermore, the NGSS endows K-12 students with authentic insights about how scientists explore the natural world while engineers design novel artifacts.

PD programs that effectively prepare teachers to design curricula, implement instructional strategies, and promote experiential learning with a grounding in the NGSS Framework necessitate consideration of myriad elements of critical importance [26]–[28] (e.g., access to curricula, suitable instructional practices, implementation support, assessment of 3D learning, program quality, content knowledge, among others). For instance, the plan and design of PD must shift from the one-day, scattershot PD model that treats teachers as passive learners [29] to a more constructivist approach [30], along with coherence in curricular and school district expectations [31], awareness of students' culture [32], familiarity with diverse learners [33], and extended learning sustained over a sufficient duration [29] to achieve deep familiarity and expertise in the NGSS [34]. The urgent need for large-scale teacher PD to support schools for effective adoption of NGSS has been highlighted recently [35]. Unfortunately, as reported in a study of NGSS-focused PD [31], participating teachers experienced significant challenges in aligning lessons to the NGSS because of (1) limited time, materials, and curricular resources and lack of continued support and (2) lack of assessments to support teacher transition away from the old science standards. According to [31], incorporating the NGSS in classroom teaching and learning was additionally challenging because new NGSS-aligned assessments were not adopted by the school districts, resulting in a mismatch between classroom instruction *vs.* the student learning outcomes.

For more than 15 years, faculty and students of the NYU Tandon School of Engineering have collaborated with teachers from New York City (NYC) schools to engage them in multi-week STEM learning experiences through authentic laboratory research and to support them in creating and delivering classroom lessons aligned with the prevailing learning standards. To support teachers in creating lessons grounded in the NGSS Framework, which address the 3D learning model, a recent offering of this multi-week PD program engaged the participating teachers in an intensive three-day workshop. The goal of this workshop was to provide PD to teachers for embedding novel technical concepts in their teaching and learning, gain an experience in designing lessons according to the 3D model of NGSS within the 5E instructional model, and address their challenges *vis-à-vis* incorporating NGSS-based lessons in classrooms.

2. Teacher Professional Development

To address the PD challenge, we designed and implemented a program to engage teachers to learn about electronics, sensors, actuators, mechanisms, microcontrollers, programming, robotics, and the NGSS through numerous hands-on activities and collaborative research. Specifically, in summer 2018, NYU Tandon hosted 11 teachers for a six-week long PD, beginning with a nine-day hands-on, guided learning of disciplinary content, followed by 18 days of collaborative engineering research experience. In contrast to the nine-day guided learning period, wherein the teachers learned various engineering fundamentals and concepts through hands-on, active learning, the 18-day collaborative research phase focused on project-based learning. By modeling and reflecting an authentic research setting, this approach engaged teachers in significant self-directed learning and collaboration with fellow researchers. As evidenced from [36], active, collaborative, and problem-based learning are found to improve student engagement, facilitate longer retention of information, and positively influence learner's attitudes and study habits.

On three days during the six-week PD, teachers participated in a lesson plan development workshop conducted by teachers and researchers of a robotics PD program, also being conducted at NYU Tandon, to explore the 3D model of NGSS and the 5E instructional model. The teachers in the NGSS-plus-5E robotics PD program were developing a curriculum to explicitly address the three dimensions of the NGSS. These teachers, supported by graduate, postdoctoral, staff, and faculty researchers, provided PD to the participants of the study reported in this paper. The goal of this PD was for the study-participants to create lessons that explicitly used their engineering laboratory experiences and grounded them in the NGSS framework. The days were organized as follow, the study-participants: (1) attended several sample lesson presentations given by the teachers of the robotics PD workshop; (2) went through the lessons as students themselves; (3) provided feedback on the robotics PD teachers' lesson design and implementation; and (4) discussed ideas for creating their own NGSS-plus-5E lessons using the engineering laboratory experiences they themselves had gained during their PD. During the summer program, each participant in this study designed an NGSS-grounded lesson plan, based on the three-day lesson development workshop as well as experiences gained from the hands-on learning activities and collaborative research.

After the guided learning phase, teachers were assigned, in two or three-person teams, to four NYU Tandon labs (Lab 1: Dynamical Systems Lab; Lab 2: Applied Micro-Bioengineering Lab; Lab 3: Applied Dynamics and Optimization Lab; and Lab 4: Mechatronics, Controls, and Robotics Lab) for observing and conducting collaborative engineering research. Observing and performing science and engineering research allowed the teachers to understand the process of approaching research questions, dissecting the core scientific principles (CCCs and DCIs), and role of SEPs in answering these questions. Thus, the teachers experienced real-world enactment of the 3D learning model of NGSS through the engineering laboratory experiences. Teachers also had opportunities to contribute to ongoing engineering research in their respective labs. Table 1 provides demographics and teacher lesson plan information.

Table 1: Teacher demographics and lesson plan particulars.

Participant	Gender	Ethnicity	Grade level	Research lab	Lesson concept addressed
A	F	Caucasian	9-12	Lab 1	Clean energy generation
B	M	Caucasian	9-10		Newton's second law
C	F	African-American	5	Lab 2	Gas laws
D	F	Asian	6-7		Engineering design process
E	F	Asian	9-12	Lab 3	Laws of gravity
F	F	African-American	9-12		
G	F	Asian	6	Lab 4	Impact of alternative energy sources
H	F	African-American	6-8		Force and pressure
I	M	Caucasian	7-12		Clean energy generation
J	M	Caucasian	9-12		Computer programming–parsing text
K	M	Caucasian	9-12		Augmented reality

3. Illustrative Examples of Teacher Research Contribution and Lesson Plan Development

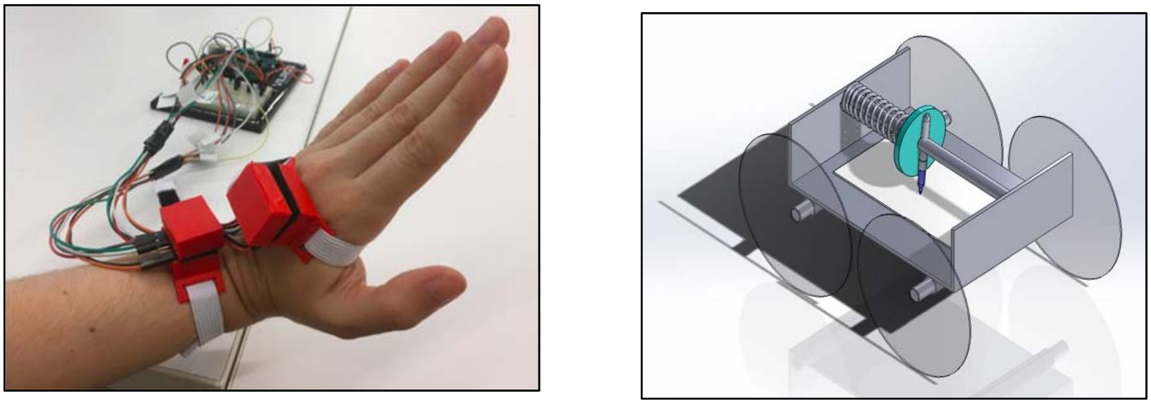
The research contributions of several participating teachers are highlighted below. Moreover, the NGSS-grounded lesson plans developed by the teachers are outlined below. For each illustrative example, the engineering research project of teachers is described in sufficient details to comprehend its role in informing the design of their lesson. For each lesson, each dimension of the NGSS 3D learning model is explicitly characterized and prompts are offered to implement the 5E instructional model.

3.1. Designing a device to measure wrist flexion of stroke patients and a lesson on accelerometer

Stroke is a primary cause of long-term adult disability in the United State [37]. Stroke survivors often have to negotiate a long and arduous path to recovery and rehabilitation of functionality. Recent years have witnessed increased interest in formulating engineering solutions to rehabilitative healthcare challenges by producing novel devices and instruments that can be used by patients at rehabilitation clinics or privately at their homes to recover and regain independence post stroke. Unfortunately, many rehabilitation protocols recommended by therapists suffer from low compliance by patients due to boredom, lack of end goal, reliance on others, etc. Thus, the goal of this engineering project is to promote the use of robot-mediated tele-rehabilitation through a low-cost system that leverages citizen science to engage patients in rehabilitation exercises, while advancing knowledge and research [38], [39]. For post-stroke hand rehabilitation, current tele-rehabilitation devices can measure the hand's position in space and forces applied by it. However, such devices are not capable of recording joint angles to infer the use of compensatory strategies for rehabilitation [40], [41]. When performing hand rehabilitation with end-effector devices, patients often experience rigid wrist flexion in their affected hand that makes is difficult to grasp and move the freely moving end-effectors. Thus, patients may adopt unnatural, non-physiological movements that defeat the purpose of tele-rehabilitation. A secondary device is therefore needed to determine the angle of wrist flexion.

Teachers A and B collaborated with engineering researchers in Lab 1 to design and prototype a goniometer sensor platform to provide the measure of wrist flexion while working with the existing rehabilitation instruments. The prototype is to serve as a proof of concept and can be enhanced to support future work in a robot-mediated tele-rehabilitation device that could be used at patients' homes. Over 18 days, teachers designed and tested circuit prototypes and programmed an Arduino microcontroller interfaced with two accelerometers. Two 3D-printed enclosures connected to straps were designed to house, position, and secure the accelerometers on a person's wrist and hand as shown in Figure 1(a). Specifically, the prototype goniometer was developed using two inertial measurement units (IMU), *viz.*, MPU 6050 IMU. One MPU 6050 was placed on the hand while the other on forearm. Movement was quantified by measuring the relative angle between the two IMUs by using their built-in accelerometers to measure the pitch and roll. Eleven neurologically intact individuals accepted to participate in the test and validation of the goniometer. The experimental data agreed with established flexion ranges. Few samples showed low flexion ranges suggesting increased difficulty for some motions by test subjects.

Acceleration measurement is quite common in many modern devices of daily use. For example, every smartphone is equipped with an IMU to measure acceleration for various applications. In a STEM lesson of teachers A and B, to understand the underlying principles of acceleration measurement, students will construct a large-scale accelerometer to measure the linear acceleration of a simple cardboard car shown in Figure 1(b). The designed accelerometer uses a small proof mass, a spring, and a marker. The students will analyze how the length of the line that the marker draws can be used to measure the acceleration of the car. This concept can be further extended to explain the principle of operation of a micro-electro-mechanical-system (MEMS) accelerometer. Lastly, students will engage in the engineering design process by proposing solutions to improve the accelerometer. The expected student learning outcomes, prior student knowledge, and the pertinent standards for this lesson are summarized in Table 2. Moreover, the details for implementing the lesson within the 5E instructional model are provided in Table 3.



(a) (b)

Figure 1: (a) IMU interface for measuring wrist flexion and (b) cardboard car for observing Newton's second law.

Table 2: Summary of learning outcomes, prior knowledge, and standards for the accelerometer lesson.

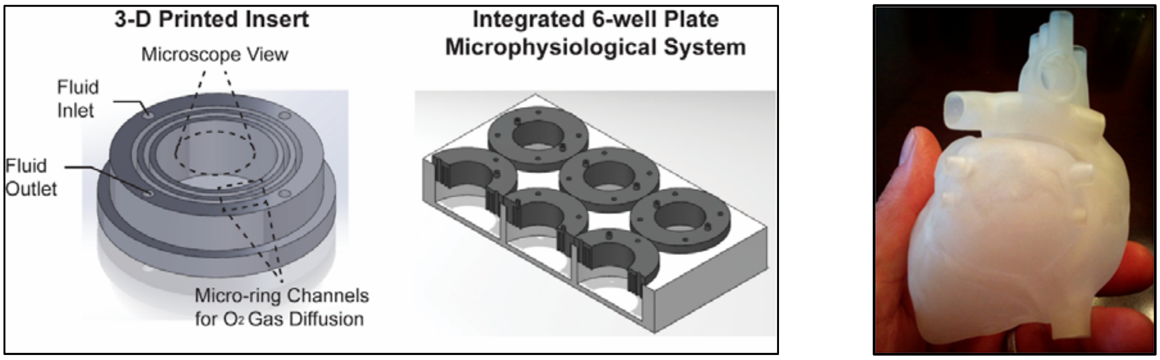
Specific learning outcomes	• Visualizing vectors • Analyze acceleration and force as vectors • Experimental analysis of Newton's second law of motion • Engage in engineering design process of an accelerometer
Prior student knowledge	Students should understand acceleration, velocity, vectors, and mass. They should know that mass is measured in kg and have a physical understanding of how heavy 1 kg is. They should also know Newton's second law as both a concept and an equation.
Supporting standard	HS-PS2-1: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
SEPs	• Analyzing and interpreting data • Developing and using models: Understanding science models, laws, mechanics, and theories explaining natural phenomenon
DCIs	PS2.A: Forces and motion
CCCs	Cause and effect: Using empirical evidence to validate claims by comparing cause and correlation

Table 3: The 5E instructional model for the accelerometer lesson.

Engage
• Download any smartphone app or game that uses accelerometer. • Place a smartphone on the cardboard car and observe acceleration readings on the smartphone while performing a simple push test. (*SEP: Analyzing and interpreting data*) • Discuss how the accelerometer readings vary with motion and what causes this change. (*CCC: Cause and effect*)
Explore
• Distribute project material required to construct the cardboard car and a simple accelerometer. Refrain from giving functional details of how the accelerometer functions. • Measure the mass of the car by using a weighing scale. • Apply a force to push the car and measure the distance it travels. (*CCC: Cause and effect*) • Investigate the relationship between the force applied and the distance travelled. (Unspecified SEP: Analyzing and interpreting data)
Explain
• Write Newton's second law and Hooke's law. • Analyze the effect of acceleration on the displacements of the spring and car. (*DCI: Force and motion*) • Provide formal definitions for relevant terms such as spring constant, force, acceleration, mass, vector, etc., and their relevance in this experiment.
Elaborate
• Identify and characterize any functional similarities between the spring-based accelerometer and smartphone accelerometer. (Unspecified CCC: Systems and system models) • Explain the functioning of the MEMS accelerometer found in smartphones. (*SEP: Developing and using models*) • Write three sentences explaining how Newton's second law can be implemented in a real situation that is not in a car.
Evaluate
• Lead a brief discussion on activity, addressing the following questions. o What would happen if a stiffer spring is used? How about a softer spring? Why? o What is the meaning of spring constant's units? o What does the length and direction of the line drawn by the marker indicate? o Why does the spring oscillate? • Using another known physics principle, propose a modification to the accelerometer car that would make it more accurate and/or precise. • Explain how it would be an improvement and how it would work. Each group will write a report detailing: o Identified limitation(s) and why they exit. o Drawings indicating any suggested modification(s). o Detailed scientific explanation of the modification(s).

3.2. Integrated and automated micro-physiological systems for monitoring organ-on-a-chip cultures and a lesson on 3D printing

Organ on a chip technology is being explored for the application of tissue engineering based approaches to develop functionally and physiologically analogous models of human organs [42], [43]. Modeling of preclinical screening of pharmaceuticals commonly requires *in-vivo* techniques. Even as the *in-vivo* techniques are currently indispensable, they suffer from myriad limitations, e.g., low throughput, long trial periods, ethical concerns, and complications associated with cross-species result transfer and validation. As a result, *in-vitro* models for screening of pharmaceuticals are gaining increasing attention to create devices with high throughputs and improve the efficiency of preclinical trials. Nonetheless, some *in-vitro* models (e.g., those based on microfluidics) may fail to replicate conditions present in the body and thus suffer due to their limited capacity to control multiple dynamic parameters simultaneously. In response, teachers C and D collaborated with engineering researchers in Lab 2 to merge open-source and inexpensive technologies like 3D printing, hardware-software interfaces, commercially-available hardware and software systems, and tissue engineering techniques, in a do-it-yourself approach, to offer a feasible solution to increase the physiological accuracy and throughput of an organ-on-a-chip. Specifically, the research team utilized a standard 6-well plate system, shown in Figure 2(a), to overcome one such dynamic problem—namely recreating O_2 [44], [45] and fluid pressure [44], [46] found in, or around, disease specific organ. The external O_2 and pressure controls dictated by the ideal gas law ($pv = NRT$) were programmed onto an Arduino microcontroller for independent controls, while 3D printed inserts, fitted onto 6-well plates, allowed users to conduct real-time cell imaging and spatiotemporal control over O_2 and fluid pressure levels for high-throughput drug screenings. In this manner, this research focused on high fidelity recreation of human physiology *in-vitro* by developing an integrated and automated micro-physiological system that can support dynamic organ-on-a-chip cultures to provide precision control over environmental conditions to achieve in-depth understanding of organ-specific diseases and improve drug efficacy.



(a) (b)

Figure 2: (a) Setup for monitoring organ-on-a-chip cultures and (b) 3D printed heart.

Additive manufacturing (such as 3D printing) technology has significantly improved the efficiency and cost of manufacturing. In the teachers' research, 3D printing technology made prototyping easier and economic. Latest research in engineering and medicine indicates the potential to create bio-engineered organs using 3D printing technology. Additionally, this technology is used to create casts for healing bone fractures. In a STEM lesson of teachers C and D, students will watch short video tutorials on how to use open source 3D design software such as SolidWorks, Cura, or Tinkercad. Working in pairs, they will select a human organ to research and develop a 3D printed model. They will draw a 3D prototype model of a shape of their own design to depict hallmarks of a specific organ and create their designs on software such as Tinkercad. Students will first scale and measure their designs to ensure timely printing and avoid exceedingly long print runs. After developing their 3D models, the students will print it out using a 3D printer (see an example in Figure 2(b)). Alternately, students may design and 3D-print parts of an organ to demonstrate its dynamic functions. For example, a heart pump can be constructed with a 3D printed hollow shaped chambers for simulating blood flow. The expected student learning outcomes, prior student knowledge, and the pertinent standards for this lesson are summarized in Table 4. Moreover, the details for implementing the lesson within the 5E instructional model are provided in Table 5.

Table 4: Summary of learning outcomes, prior knowledge, and standards for the 3D printing lesson.

Specific learning outcomes	• Design 3D models using SolidWorks, Cura, or Tinkercad software • Prototype design using 3D printer • Understand the importance of precise dimensioning while designing • Design and print model of a human organ
Prior student knowledge	Students must be familiar with cellular organization and how it forms the different body systems.
Supporting standard	K-2-ETS1-2: Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps its function as needed to solve a given problem.
SEPs	Developing and using models: Develop a simple model based on evidence to represent a proposed object or tool
DCIs	ETS 1.B: Developing possible solutions
CCCs	Structure and function: Shape and stability of natural and designed objects are related to their functions

3.3. Initiating stable gait in a passive walker and a lesson on passive walker

Robot walkers based on passive-dynamic walking exploit gravity to power their locomotion [47]. Constructed with rigid parts connected by joints, such robots can imitate human-like gait to demonstrate the simple mechanics of bipedal walking on a level or downward sloping surface. When endowed with actuators, these robots acquire the ability to walk uphill and traverse different types of terrains [48]. In this effort, teachers E and F, collaborating with engineering researchers in Lab 3, sought to study the initiation of gait in a partially actuated passive walker based on Rando, an open-source design [49] (see Figure 3(a)). Rando employs a microcontroller that extends and retracts its legs by controlling servomotors. Its simple design and control make Rando a desirable platform to study the energy expenditure and balance stability of legged systems. Furthermore, as an inexpensive device (with parts printable for < $50), it permits researchers with limited access to funds, equipment, and prototyping facilities to conduct research on passive dynamic walking. Teachers E and F were tasked with developing a device to initiate a stepping motion for inducing stable gait in the passive walker. The device would impart the momentum needed to launch the passive walker in a consistent manner, limiting variability in the achieved gait. Based on observations of the robot in motion, two designs were developed using SolidWorks and 3D printing. The first design was a ramp-like structure with a concave face to hold the passive walker's internal pair of legs in place and a well for the spring actuator (see Figure 3(b)). The second design was a launcher (see Figure 3(c)) constructed from wood and 3D printed PLA components with an internal spring and a horizontal crossbar to provide force to Rando's internal pair of legs to set the walker in motion. Future work will include rigorous evaluation and comparison of both designs to develop adjustable devices that can achieve variable sets of initial conditions for stable gait.

Table 5: The 5E instructional model for 3D-printing lesson.

Engage
• Have you ever seen how a 3D printer works? (Students explore articles from fields that benefited from 3D printing technology [50], [51]). • What are the different things you can create using the 3D printing technology? (*SEP: Developing and using models*) • Do the advantages of using 3D printing technology outweigh the disadvantages (e.g., 3D printing biological microfluidic devices *vs*. 3D printing guns)?
Explore
• Students will watch short video tutorials on how to use the open source versions of 3D design software such as SolidWorks, Cura, or Tinkercad. They will read and annotate handouts that explain how to use these software interfaces. • After watching the tutorial and reading handouts, students will explore the given software and write notes on a journal to describe their experience on the usability of each software. • Students can also design and 3D print parts of an organ and show how it works. For example, they can construct 3D printed hollow shaped compartments that will show the flow of blood within the heart organ. (*DCI: Developing possible solutions*)
Explain
• How different is it to make a design using a preset shape *versus* a free hand shape? (*CCC: Structure and function*) • How will you create hollow sections inside a given shape? (*DCI: Developing possible solutions*) • How can shapes be grouped into one object? • How can we use software interfaces to design models that simulate organ function? (SEP: Developing and using models) • Is it better to make a modular design or one big print? • How do you ensure that the objects you make correspond with the parameters (e.g., size) of the model? • If you are asked to design and 3D print a bioengineering tool/device/model, how would you go about doing it?
Elaborate
• Explain the iterative design process through an example. • Develop and critically analyze a case study of 3D printing technology utilization. • Provide technical and functional details of the underlying technologies that enable 3D printing and computer aided design (CAD).
Evaluate
• Lead a brief discussion on activity, addressing the following questions. o How is a design process initiated? o How can we compare modern CAD design techniques with traditional ones? o How do 3D printers work? What can we print using these? o Do we need 3D printing? Why? o How can the 3D printing technology be further improved? o Can 3D printing be environment-friendly? • Students will use journals or blogs to highlight their designed 3D models. • Handout homework for students to design any item of their choice and save it as an STL file to be printed at school.

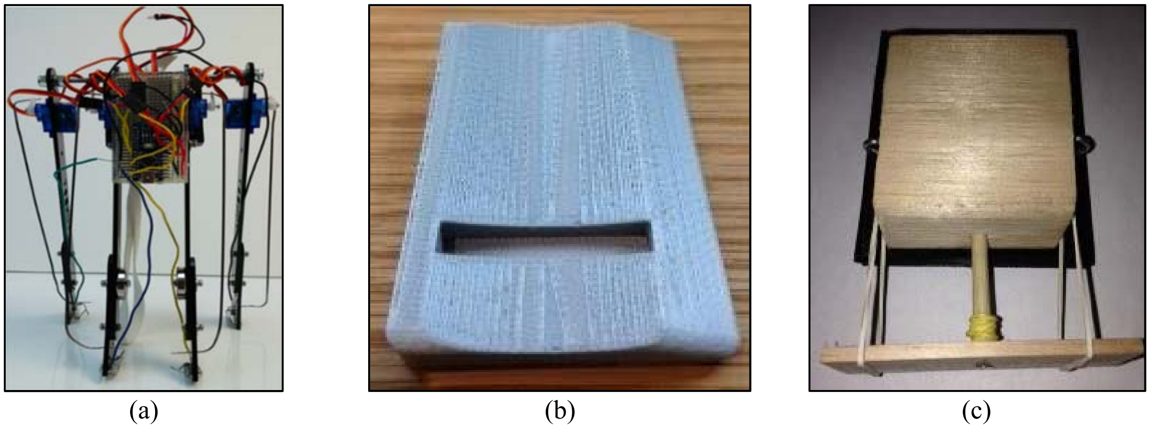

(a) (b) (c)

Figure 3: (a) Dynamic passive walker, (b) 3D printed ramp, and (c) launcher mechanism.

In a STEM lesson of teachers E and F, students will watch videos to understand the concept of passive walkers. Later, they will construct a two-legged mechanism that can walk down a gentle slope using dowels and binder clips with no energy source other than gravity and no active feedback control. They will be exposed to open source design and will work in groups to design their own passive walker and test the stability and efficiency of their walker. If a 3D printer is available, they will create a Rando walker using the open source files, as shown in Figure 3(a). The expected student learning outcomes, prior student knowledge, and the pertinent standards for this lesson are summarized in Table 6. Moreover, the details for implementing the lesson within the 5E instructional model are provided in Table 7.

Table 6: Summary of learning outcomes, prior knowledge, and standards for the passive walker lesson.

Specific learning outcomes	• Examine the engineering design process (EDP) • Collaboratively prototype a passive walker • Use EDP to create a simple passive walker
Prior student knowledge	Students should understand basic geometry and Newton’s laws of motion.
Supporting standard	HS-ETS1: Analyze a challenge and identify constrains. Breakdown and design a solution through engineering. Evaluate the solution using simulated model or prototype.
SEPs	Using mathematics and computational thinking
DCIs	ETS1.A: Defining and delimiting engineering problems ETS 1.B: Developing possible solutions ETS 1.C: Optimizing design solution
CCCs	Systems and system models: Models can be used to simulate systems and interactions within and between systems at different scales

Table 7: The 5E instructional model for passive walker lesson.

Engage
• Show a demonstration video of a passive walking robot. • Have a discussion on how engineers initiate, execute, and evaluate a design process of a walking robot. (*DCI: Defining and delimiting engineering problems*) • Pose the following questions to initiate discussion and evaluate student knowledge. o How was this robot created? Where did they start? o Did someone do it alone? How did s/he come up with this idea? o Do you think this robot was created in one fell swoop? If not, how long might it have taken? o What are the qualifications of those who designed this robot?
Explore
• Allow the students to map out a plan to design a walking robot. (*CCC: Systems and system modeling*) • Examine the scientific and engineering tools required to build the robot. • Using provided instructions and material, build a simple passive walking robot. (*DCI: Developing possible solution*)
Explain
• What are the forces involved in initiating walking motion in the passive walker? (*SEP: Using mathematics and computational thinking*) • Explain the importance of engineering design process in a project. • How is the EDP initiated and executed in large-scale projects. Use one or more NASA projects as example [52]. • Provide detailed overview of the passive walker project, from identifying the challenge to evaluating the prototype. (*CCC: Systems and system modeling*)
Elaborate
• How can the passive walker performance and stability be improved? (*DCI: Optimizing design solution*) • Investigate the effects of **not** using the EDP. • Provide details about the effects of EDP on time, cost, and the project team's performance efficiency.
Evaluate
• Observe students as they comment on the video during discussion. Note what students already know and any misconceptions that they may have. • Record and analyze any questions they pose. • Examine student's design approach and analyze the performance and stability of the walking robot.

3.4. Identifying agents in a decentralized swarm and an augmented reality lesson

Swarm robotics is increasingly being utilized in commercial and tactical settings [53]. Current systems, such as those implemented by Amazon and Intel feature centralized strategies, where all robots in the swarm are controlled by a central server. The centralized strategies can potentially fail if the central server is faulty or if communication is disrupted, causing large-scale malfunctions. Thus, this research explored the possibility of implementing a decentralized scheme for controlling swarm robots. Specifically, a distributed protocol was devised to identify individual robots in a swarm and peer-to-peer communication was used for identification. However, decentralized systems do not offer supervised control of its agents like a centralized system. This complicates the human-robot interaction, making it difficult to pass instruction to the robots. A smart device with an augmented reality (AR) app provides an effective solution to this limitation due to its wide availability and computational capabilities. Teachers J and K collaborated with engineering researchers in Lab 4 to create an AR smartphone app with a user-interface to control the swarm robot actions. Through the AR interface, the user can independently control the swarm while giving commands to a leader robot, which broadcasts the instructions to its neighbors. Swarm robots are shown in Figure 4 (a). The application was integrated with the Robot Operating System (ROS) environment to communicate with the robots. Focusing specifically on developing an application that visually expresses the accuracy of formation control in a decentralized system, the app interface also included a graphical representation of the movement of the robots with respect to their expected positions. Replacing colored tags-based detection, leveraging on their accuracy and robustness, AprilTags (Figure 4(b)) and cartoon images were used to identify the robots [54]. Augmented reality layer of the app added AR overlays (Figure 4(c)) on the detected robots for visualizing their current positions.

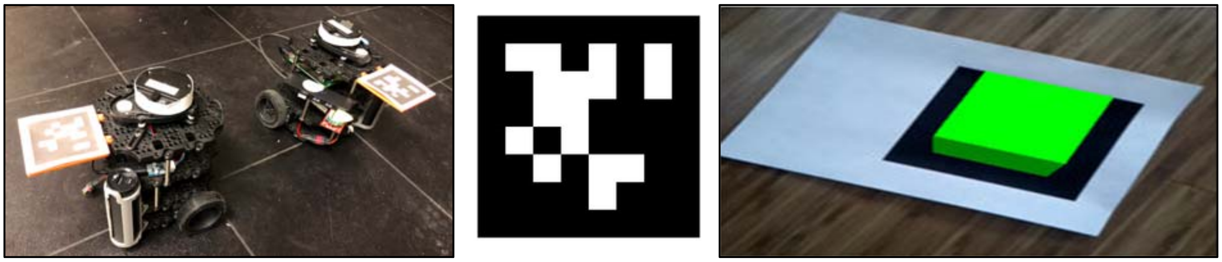

(a) (b) (c)

Figure 6: (a) AR robot environment, (b) an AprilTag, and (c) AR overlay projection.

AR is a frontier technology that has become pervasive in entertainment and gaming industries. This powerful technology has tremendous potential for creating intuitive user interfaces for robotics and medical fields [55], [56]. Advances in smartphone technology have significantly increased the computational capacity of mobile devices. Smartphone apps can now perform complex computations with relative ease. Thus, AR can easily be implemented on smartphones using simple app-building instructions. In a STEM lesson of teachers J and K, students will explore the working principles of AR technology through smartphone enabled apps and fiducial markers such as AprilTags, shown in Figure 4(b). Students will also explore the potential of AR and smartphone technology implementation through real-world examples. The expected student learning outcomes, prior student knowledge, and the pertinent standards for this lesson are summarized in Table 8. Moreover, the details for implementing the lesson within the 5E instructional model are provided in Table 9.

4. Observations and Discussion

Throughout Tables 3, 5, 7, and 9, which outline the 5E instructional sequence for four lessons, numerous opportunities for incorporating the three dimensions of the NGSS are explicitly identified. Nonetheless, a careful review of these tables reveals that multiple additional components of the 3D model of the NGSS are embedded therein but remain unspecified. As an illustration, in Table 3 we have identified one unspecified SEP (Analyzing and interpreting data) and one unspecified CCC (Systems and system model). This reveals that the 5E instructional framework offers a highly flexible platform to incorporate the three dimensions of the NGSS [20].

Although educators are increasingly recognizing the need to adopt NGSS for curriculum and instruction, they lack access to readily available and widely applicable NGSS-grounded materials. Moreover, there is a paucity of PD resources to impart teachers the required experience and support in creating such high-quality material on their own. Even as curriculum developers seek to fill this void, there is an urgent need to perform valid evaluation for assessing the quality of the newly developed materials. As one response to the aforementioned needs, the participants in the PD program of this paper successfully developed several lesson plans. Nonetheless, due to time limitations of PD, several lessons developed by teachers did not undergo the entire lesson development process (e.g., responsiveness to the three dimensions of the NGSS and formulation within the 5E instructional framework). Moreover, PD participants sought supplemental feedback on lessons as a critical step. To address the aforementioned limitations, future PD programs will devote a longer duration for developing, reviewing, revising, and evaluating lessons and integrated feedback from PD participants, researchers, and education experts. Educators Evaluating the Quality of Instructional Products (EQuIP) rubric and the corresponding review template provide evidence of quality and degree to which any curricula or instructional material is aligned to the NGSS [57], [58] and assure that the instructional material adopted for classroom use is of high quality. Specifically, the rubric of [57] was developed to extract consistency and agreement in NGSS-aligned lessons and units by assessing 19 indicators in three categories consisting of *NGSS 3D design*, *NGSS instructional support*, and *monitoring NGSS student progress*. In future iterations of the PD program, the NGSS-grounded lessons of participants will be analyzed by adopting and using the EQuIP rubric.

Table 8: Summary of learning outcomes, prior knowledge, and standards for the AR lesson.

Specific learning outcomes	• Smart-phone app development • Understand projection geometry and relative transformations • Understand rotation, translation, and scaling principles • Camera usage and computer vision
Prior student knowledge	Students should have basic understanding of programming and geometry
Supporting standard	HS-ETS1-4: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
SEPs	Using mathematics and computational thinking
DCIs	ETS 1.B: Developing possible solutions
CCCs	Systems and system models: Models can be used to simulate systems and interactions within and between systems at different scales

Table 9: The 5E instructional model for AR lesson.

Engage • Demonstrate an AR application on smartphone. • Task the students with downloading and demonstrating an AR app of their choice from the app store. • Discuss the functionality of AR in these apps and how it affected the app's usability and popularity.
Explore • Use the provided code template to create AR objects of various shapes and sizes. (*DCI: Developing possible solutions*) • Investigate how the AR projection is affected by change in camera angle. (*SEP: Mathematics and computational thinking*)
Explain • Examine the code template and explain the function of each section. • Present the designs to the class and receive feedback. • Provide detailed explanation on relative transformations. (*SEP: Mathematics and computational thinking*)
Elaborate • What conditions will affect the AR projection? • How does a bad marker affect the tag? How can you remedy this? • Can you use an alternative tag instead of an AprilTag? • How do robots navigate inside a warehouse or mall? (*CCC: Systems and system modeling*)
Evaluate • Students are tasked to calculate the scale, rotation, and translation of the 3D object they created to fit on a fiducial marker. (*SEP: Mathematics and computational thinking*) • Students team up with a partner to create an AR projection using the provided code template. • Present challenges to the students by changing the lighting conditions, marker angle, and marker size. • Inquire the thought process followed by the student in determining the reason for unsuccessful AR projection on the tag and how to overcome those.

5. Conclusion

During the six-week PD program, teachers first familiarized themselves with foundational engineering concepts through guided learning experiences with hands-on explorations. Next, by joining as members of research teams in participating labs, teachers began engaging in collaborative engineering research. Some teachers experienced working in a research environment for the first time, while another subset of teachers learned about the various engineering concepts such as programming, electronics, etc., for the very first time. They gathered a variety of information and gained diverse practical experiences during the guided-training and research experience phases. By participating in a three day PD workshop focused on learning about and creating NGSS-grounded lesson, the PD participants created several lesson plans to share their newly acquired knowledge with students and colleagues. The newly designed lessons followed the three dimensional learning model of the NGSS and incorporated the 5E instructional model. Future efforts will focus on formal assessment of teacher-developed lesson plans by using the EQuIP rubric.

Acknowledgments

This work is supported in part by the National Science Foundation grants RET Site EEC: 1542286, DRK-12 DRL: 1417769, and ITEST DRL: 1614085; and NY Space Grant Consortium grant 76156-10488. The authors thank the 11 NYC teachers for their participation in this study. Moreover, the authors thank (i) the faculty research mentors; (ii) graduate student collaborators of teachers; (iii) NYU Tandon's Center for K-12 STEM Education and Incubators Initiatives; and (iv) industry partners for their support.

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