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ANALYSIS AND INCORPORATION OF NGSS INTO EXISTING SCIENCE CURRICULA

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Analysis and Incorporation of NGSS into Existing Science Curricula

Synopsis:

This paper describes a science department's exploration and evaluation of NGSS as it relates to their existing Gr. 6-12 science curricula. It outlines the process of understanding NGSS, analyzing existing curricula as it relates to NGSS, and incorporating new content, including insights and challenges faced.

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Introduction

University Laboratory School (ULS) is a public charter school that operates in partnership with the Curriculum Research & Development Group (CRDG), a research unit within the College of Education at the University of Hawai‘i. The school serves as an experimental site for research and development in teaching, learning, and assessment in grades K–12 while providing a high quality education for all students. As part of the school's research design, students represent a socio-economic, geographical, intellectual, and ethnic cross-section of the public school population of the State of Hawai‘i. All students are enrolled in heterogeneous classes by grade level, taking the same academic courses.

The University Laboratory School's vision is that "all students graduate ready for college, work and responsible citizenship. The school serves two interlocking missions: to design and deliver the best possible education to its students, and to serve the educational research and development community as an inventing and testing ground for high quality educational programs (ULS, 2015)."

In 2013, ULS began preparing for the accreditation process, which included an examination of its current practices and curricula. During this review, the Next Generation Science Standards (NGSS) emerged as a feasible nation-wide initiative for aligning curricula. The NGSS are new education standards that are "rich in content and practice, arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked science education (NGSS, n.d.)." The NGSS are seen as guidelines that are intended to help students understand the nature of science while learning scientific skills and habits of mind. The State of Hawaii adopted NGSS in February 2016. As a demonstration site for research-based methods of direct experience, hands-on activities, and higher order intellectual processes, it is essential that the ULS curricula continues to reflect the goals of the Hawaii Department of Education (DOE).

The ULS science department teaches disciplinary inquiry through authentic learning experiences. Teachers are facilitators of group interaction and learning. Learners construct and build on their own knowledge and understanding from their experiences working on investigations in small collaborative groups. This common knowledge is developed and clarified within the learning community. The science department consists of four classroom teachers who teach both middle and high school courses in grades 6-12 (Table 1).

Currently the 6th through 8th grade science classes use the *Foundational Approaches in Science Teaching (FAST)* curriculum. The FAST curriculum was created in the late 1960s by the University of Hawai'i at Manoa's CRDG and was developed based on the theory that students construct their own knowledge and understanding by participating in authentic science experiences and investigations. FAST activities are organized into three strands: physical science, ecology, and interrelationships among science, technology, and society. Ninth grade Marine Science: *The Fluid Earth and The Living Ocean* and tenth grade *Practices in Physics and Technology* (PPT) were designed similarly to the FAST curriculum in that they engage students in hands-on learning within specific disciplinary content. Over the years, the knowledge and skills learned by eleventh grade chemistry and twelfth grade biology students has varied depending on the instructors hired to teach the course. Currently, the chemistry curriculum is based on the National Science Education Standards (NSES) supplemented with select standards from other states. Similarly, the current biology curriculum has been designed using both The

College Board AP Biology curriculum and NSES as templates. As described here, none of the current science curricula have been designed or altered to address the NGSS.

Table 1. Science department instructors by grade level

Instructor	**Grade Level**	**Subject Area**
H. Holm	6	FAST 1
J. Seki	7	FAST 2
B. Skiles	8	FAST 3
J. Seki	9	Marine Science
S. Alam	10	PPT
B. Skiles	11	Chemistry
H. Holm	12	Biology

Project Work Plan

In order to carry out the research project, the science department needed professional development time to collaborate within the school day. The process spanned three school years involving a total of eight full work days (Table 2 and Figure 1).

Table 2. Workdays per phase

Phase	Description	Number of Professional Development Days
1	Understanding NGSS	1
2	Analysis of Current Curricula with NGSS	3
3	Revising Curricula and Incorporating New Content	4 + individual planning time throughout school year

NGSS Alignment Phase Progression

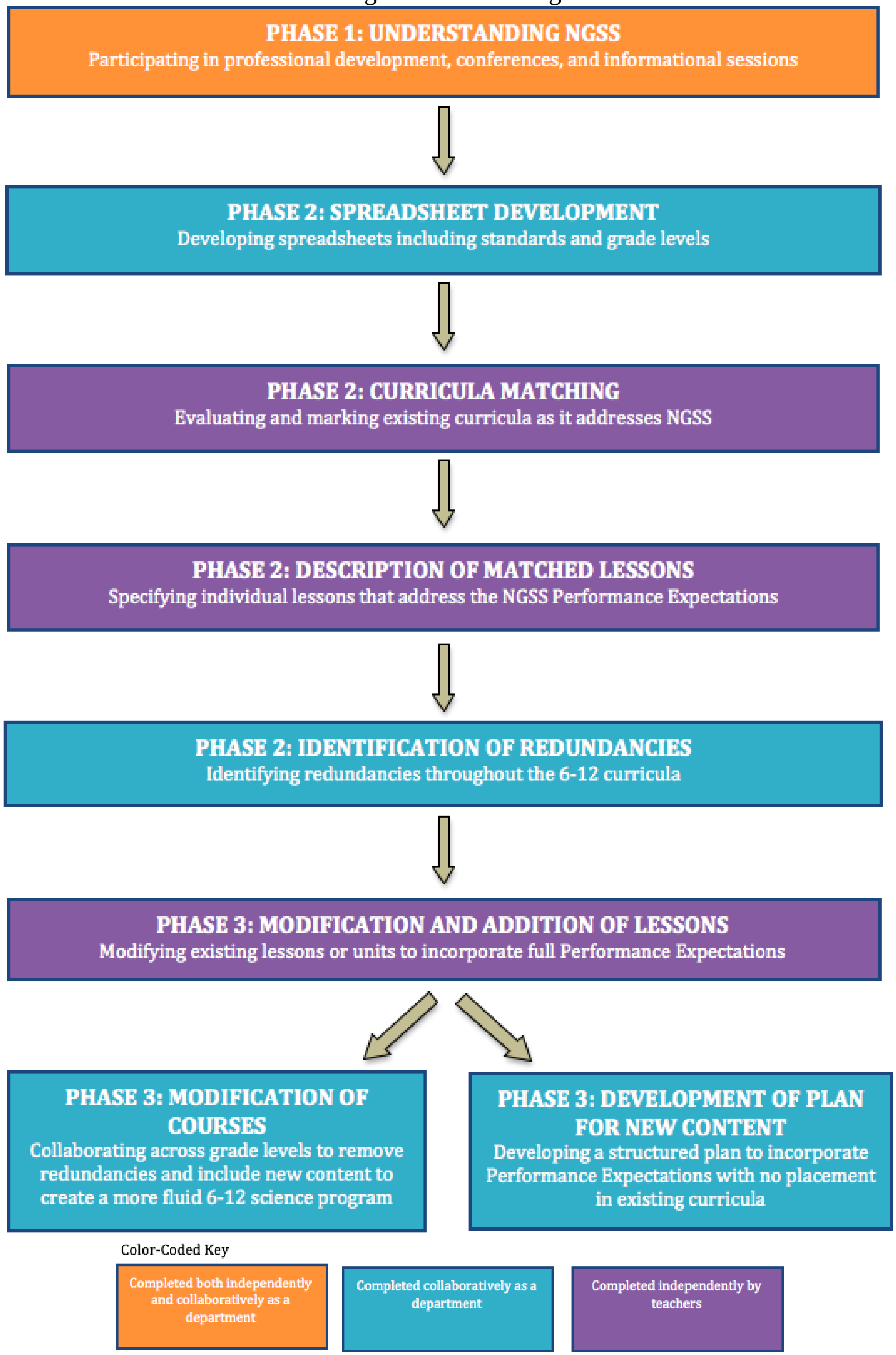

Figure 1. Work Plan Flow Chart

Phase 1. Understanding NGSS

The science department familiarized itself with NGSS Performance Expectations (PEs), Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and Science and Engineering Practices by first reading through grade level standards individually. Teachers shared and discussed their prior experiences and knowledge of NGSS which included sessions at NSTA conferences, attendance at the San Diego Science Education Association (SDSEA) Next Generation Science Conference, exposure through graduate coursework in education, informational session with the Hawaii DOE Science Education Specialist, and district level professional development focused specifically on understanding NGSS and developing lessons to address PEs.

When NGSS was initially reviewed, the focus was on the PEs. At first glance, these did not seem to align well with the topics covered in the curriculum. Later, it was realized that these are the end goals for student learning and do not describe the scaffolding process that needs to occur in order to meet the expectation. It is actually the DCIs that outline the key concepts needed to reach the PEs. In light of this realization, a second review was conducted, which revealed that there was a closer alignment than previously thought.

Currently more resources are available than at the start of this project. The NGSS website and other online sites provide tools that could be used to better understand the organization of NGSS and how the dimensions should work together to provide authentic learning experiences for students. Videos with overviews of NGSS and demonstrations of each of the three dimensions are featured on the NGSS, NSTA, and Teaching Channel websites (NGSS, n.d.; NSTA, 2015; NSTA, 2016; Teaching Channel, 2016). Resources for evaluating lessons and/or units with respect to NGSS standards and PEs are also available. Several of these resources with brief descriptions are shown in Table 3.

Table 3. NGSS Resources

Resource	Link	Description
Videos Explaining NGSS	Overview • NGSS: A Vision for K-12 Education (Teaching Channel) • Next Generation Science Standards: Introduction to Three Dimensional Learning (NSTA) • Next Generation Science Standards: The Vision for Science Education and the New Role of Teachers (NSTA) Disciplinary Core Ideas • Disciplinary Core Ideas (Teaching Channel) • NGSS: Core Ideas and Cross-	Videos explaining and demonstrating the three dimensions of NGSS

	Cutting Concepts (NSTA) Science and Engineering Practices • Science and Engineering Practices (Teaching Channel) Crosscutting Concepts • Crosscutting Concepts (Teaching Channel)	
NGSS Video on Reading the Standards	Reading Next Generation Science Standards	Video providing an overview of how to read the NGSS.
NGSS Three Dimensional Learning	NGSS Three Dimensional Learning	NGSS website with information on Practices, Crosscutting Concepts, and Disciplinary Core Ideas
NGSS Evidence Statements	Evidence Statements	NGSS website providing educators with additional detail on what students should know and be able to do. These are statements of observable and measureable components that, if met, will satisfy NGSS PEs.
EQuIP Rubric for Lessons & Units	Rubric for Lessons & Units How to Select and Design Materials that Align to the Next Generation Science Standards (NSTA Community Blog) Teaching Channel Video	Rubric providing criteria by which to measure the alignment and overall quality of lessons and units with respect to the NGSS, and supporting materials on how to use it

Phase 2. Analysis of Current Curricula with NGSS

Spreadsheet Development. A spreadsheet was created to align middle and high school NGSS PEs with ULS science courses (Figure 2). Columns were included for the NGSS Standard IDs, Descriptions of PEs, as well as eachgrade level, 6-12. The NGSS standard IDs and Descriptions of PEs were then added to the spreadsheet from the NGSS website. Throughout the remainder of this process, the spreadsheet was a dynamic document that reflected progress and changes made. Color coding was added at various points to categorize the status of the standards as it related to the ULS curricula (Figure 3).

Figure 2. Overview Alignment of Middle and High School NGSS PEs

NGSS Standard	Description	6	7	8	9	10	11	12
MS-PS1	Matter and Its Interactions							
MS-PS1-1	Develop models to describe the atomic composition of simple molecules and extended structures.		X	X	X		X	
MS-PS1-2	Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.		X		X		X	
MS-PS1-3	Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.		X	X				
MS-PS1-4	Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.	X	X		X		X?	
MS-PS1-5	Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.		X				X	
MS-PS1-6	Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.		X					
MS-PS2	Motion and Stability: Forces and Interactions							

Overview | Gr 6 | Gr 7 | Gr 8 | Gr 9 | Gr 10 | Gr 11 | Gr 12

Figure 3. Color-coded key for spreadsheet

Yellow	Not previously addressed in our curriculum	Red	Was being taught but no longer needs to be emphasized
Green	Addressed in a different grade level and want to add to correct grade level	Magenta	Not addressed at all in the current curriculum and no reasonable place to include it

Curricula Matching. Each teacher then indicated in the spreadsheet which standards were addressed and in which grade with an “X”. An “X?” indicated that the individual teacher was unsure if the PE was addressed in sufficient depth (Figure 2).

Description of Matched Lessons. Additional sheets were created for each grade level for teachers to elaborate on the specific lesson(s) that address each PE (Figure 4). Teachers copied the relevant Standard ID and Description to their individual grade level sheet, added the Lesson ID/Descriptor, included specific concepts and tasks for those lessons, and added additional comments as needed. Teachers referenced textbooks, teacher guides, lesson resources, and student samples in order to confirm the standard placement.

Figure 4. Grade 9 NGSS PEs with Lesson ID and Descriptor

	A	B	C	D	E
1	**GRADE: 9**				
2	NGSS Standard ID	Description	Lesson ID or Descriptor	Concepts/Tasks	Comments
3	**PS1 Matter and Its Interactions**				
4	**MS-PS1-1**	Develop models to describe the atomic composition of simple molecules and extended structures.	FE CHEM 1-0 Matter, FE 5-0 Water	Construct a concept map of chemical terms (atom, molecule, soild, liquid, gas).	
5	**MS-PS1-2**	Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.	FE 2-2 Water Layers?	Layers of water of different salinities and temperatures are mixed to simulate movement of water layers in the ocean during ocean circulation.	Only density and solubility are mentioned.
6	**MS-PS1-4**	Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.	FE 2-4 Vertical Water Movement; FE 2-5 Thermohaline Circulation	The effects of differences in salinity and temperature on relative density are studied in the ocean as the driving factors in ocean circulation.	
7	**HS-PS1-1**	Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.	FE CHEM 2-1 Recovering Salts from Seawater; FE CHEM 2-2B Elemental Abundance in Nature	FE CHEM 2-1 Seawater is evaporated to recover, describe, and quantify salts (sodium chloride). FE CHEM 2-5 Trends in the periodic table are studied to understand patterns in chemical bonding.	

Overview | Gr 6 | Gr 7 | Gr 8 | Gr 9 | Gr 10 | Gr 11 | Gr 12

Next, the standards marked with "X?" (unsure if the PE was addressed in sufficient depth) were reexamined (Figure 2). Disciplinary Core Ideas and the Crosscutting Concepts were used to clarify the meaning of each PE. As a team it was discussed whether or not the lesson or unit in question did in fact enable the student to meet the PE. If it was determined that the lesson did meet this need, the "?" was removed. If not, these lessons were highlighted in yellow and teachers had a preliminary discussion on possible placement within the curriculum. These lessons were then re-evaluated in Phase 3.

Middle school standards that were only addressed in the high school curricula were then looked at more closely. It was determined where, if possible, they could be incorporated into the middle school curricula based on whether or not it enriched the content (Figure 5). For example MS-PS3-1 *(Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.)* and MS-PS3-2 *(Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.)* are middle school standards only taught during 10th grade PPT. Through discussion it was decided that MS-PS3-2 could be taught in the 8th grade curriculum and was appropriately marked, because topics in energy are also taught in FAST 3.

Figure 5. Middle School Standard Only Addressed in High School

2	NGSS Standard ID	Description	6	7	8	9	10	11	12
16	**MS-PS3**	**Energy**							
17	**MS-PS3-1**	Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.					X		
18	**MS-PS3-2**	Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.			X		X		
19	**MS-PS3-3**	Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.		X					
20	**MS-PS3-4**	Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	X						

Identification of Redundancies. Areas of redundancy were recognized within certain curricula. Specifically, redundancies were identified as PEs that were being taught in multiple grade levels and did not add significantly different content or ideas. At this point, the team discussed where the redundancies within curricula could be eliminated. This often included an in depth discussion of the level of complexity of the topic within the lesson or unit. It was then determined which course would best highlight that PE and where it could be minimized or eliminated, indicated in the spreadsheet by highlighting in red) (Figure 6).

Figure 6. Redundancies

2	NGSS Standard ID	Description	6	7	8	9	10	11	12
35	**MS-LS2**	**Ecosystems: Interactions, Enrgy, and Dynamics**							
36	**MS-LS2-1**	Analyze and interpret data to provide evidence for the effects of resource availability in organisms and populations of organisms in an ecosystem		X	X	X			X
37	**MS-LS2-2**	Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems		X	X				X
38	**MS-LS2-3**	Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem		X	X	X			X
39	**MS-LS2-4**	Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations		X	X	X			X
40	**MS-LS2-5**	Evaluate competing design solutions of maintaining biodiversity and ecosystem services*			X				

Phase 3. Revising Curricula and Incorporating New Content

Modification and Addition of Lessons. Previously unaddressed standards were discussed and PEs or topics that could be easily incorporated into the existing curricula were placed where they would enrich the course of study. In some cases, new lessons and/or units needed to be created and in other cases, current lessons and/or units needed to be expanded. Goals were made to incorporate the new content within the current or following school years.

For example, in HS-PS2-3 *(Apply scientific and engineering ideas to design, evaluate and refine a device that minimizes the force on a macroscopic object during a collision)*, physics students did design a device involving collision, however minimizing the force on the object was not emphasized in the lesson. Through discussion with the team, the teacher determined that refining the existing lesson to include preserving a raw egg upon collision with the ground (minimizing the effect of the force upon impact) as well as minimizing acceleration due to gravity would address the complete PE (Figure 7).

Figure 7. Example of a lesson modified to incorporate the full PE

NGSS Standard ID	Description	Lesson ID or Descriptor	Concepts/Tasks	Comments
HS-PS2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	Mechanics I - Investigation 9: Gravity and Acceleration	Design a device to have an acceleration less than g (gravity)	They do not yet design a device to minimize force on an object during collision: Could do an egg drop

For each unaddressed PE, it was discussed as a team if it could be included within the current scope and sequence of the courses. If so, the course(s) in which it would be most appropriate were identified. In Figure 8, MS-ESS3-1 *(Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes)* was indicated as not currently addressed in any grade level course. A question mark indicated that the 8th grade curriculum would be the most logical fit because students explore plate tectonics and changes in the earth over time. Knowledge of plate movements could be applied to explain how earth's mineral, energy, and groundwater resources are distributed unevenly across the earth's plates (Figure 9).

Figure 8. Example of performance standard not currently addressed in any course

2	NGSS Standard ID	Description	6	7	8	9	10
63	**MS-ESS2**	**Earth and Human Activity**					
64	**MS-ESS3-1**	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.			?		
65	**MS-ESS3-2**	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.			X		
66	**MS-ESS3-3**	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*	X?	X	X?	X?	
67	**MS-ESS3-4**	Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.		X	X	X	
68	**MS-ESS3-5**	Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.			X	X	
69	**MS-ETS1**	**Engineering Design**					
70	**MS-ETS1-1**	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevent scientific principles and potential impacts on people and the natural environment that may limit possible solution		X	X		

Overview | Gr 6 | Gr 7 | Gr 8 | Gr 9 | Gr 10 | Gr 11 | Gr 12

Figure 9. Example of performance standard that could be incorporated into grade 8 curriculum

NGSS Standard ID	Description	Lesson ID or Descriptor	Concepts/Tasks	Comments	Links
MS-ESS3-1	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.	LESSON TBD - Could be included in Unit 7 with focus on energy resources		Currently no focus on mineral or groundwater resources	

At this point in Phase 3, the middle school curriculum had two remaining unaddressed standards which were taught in the high school physics course. Proper placement in the middle school curriculum needed to be determined. The high school curriculum had unaddressed standards in the areas of engineering design and earth and space sciences (ESS). Engineering design practices are essential to a comprehensive science education, therefore goals to incorporate them into the high school curricula were made (Figure 10). Plans to incorporate engineering design practices were made for each course, starting in 9th grade with the most basic skills and progressing to 12th grade with the most complex. For example, HS-ETS1-1 *(Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants)*, asks students to analyze an existing issue along with possible solutions. As this is the foundation for more complex and abstract thinking, it made sense to incorporate it into the foundational high school science course. As the engineering practices progress to 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)*, students create and evaluate an original solution to an existing global issue. As this practice is the most abstract level of thinking, it is appropriate to place it in the capstone high school science course. At this point, the department needs further collaboration to develop a rubric for progression of these engineering practices.

This is one way to approach incorporation of the engineering practices into curricula that previously did not focus on engineering. It is understood that multiple standards can and should be addressed in a single grade level, although this plan allows for a progression of mastery of each practice throughout the high school curricula.

Figure 10. Engineering Design Practices Broken down by Grade Level

NGSS Standard ID	Description	6	7	8	9	10	11	12
HS-ETS1	**Engineering Design**							
HS-ETS1-1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.							
HS-ETS1-2	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.							
HS-ETS1-3	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.							
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.							

Next, teachers worked individually throughout the school year to incorporate and/or modify lessons to reflect the new alignment. Throughout this process, teachers shared their progress within the department and offered feedback, support, and suggestions to facilitate further development of those lessons.

Modification of Courses. Teachers worked collaboratively to modify different grade level course curricula to remove redundancies and address new content in order to improve the fluidity and cohesiveness of science curricula from year to year. For example, the middle and high school earth and space sciences standards MS-ESS3-5 *(Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century),* and HS-ESS3-5 *(Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems)* were previously taught only from the marine perspective in the 9th grade marine science course and not at all in middle school. Teachers identified ways to introduce climate change from atmospheric and terrestrial perspectives in 8th grade to provide a foundation of understanding that can be built upon in 9th grade when students learn about ocean acidification. Another example would be students learning moon phases in 8th grade and using that knowledge in 9th grade when learning about ocean tides.

Development of Plan for New Content. At the end of Phase 3, a plan was made to incorporate the essential concepts that had no placement in any of the existing curricula. For example, the PPT physics curriculum focuses primarily on mechanics and does not include time within the school year for topics in light, sound, electricity, and magnetism. To incorporate these topics, the mechanics units were condensed to allow for new lessons to be implemented. This process enables closer alignment of the curriculum to NGSS.

Conclusion/Next Steps

This overall alignment process confirmed the notion that ULS 6-12 science program meets current national and international science education expectations, and served as a professional development tool for better understanding the comprehensive and progressive nature of the science curricula. Teachers will continue to refine, develop, and evaluate lessons to articulate specific NGSS PEs. Evaluation of lessons will include utilizing NSTA and NGSS resources such as the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric.

During the process, teachers gained a deeper understanding of NGSS and were able to identify where standards were addressed, giving them a comprehensive look at the curricula. Furthermore, as a department, a cohesive plan was developed to enrich existing content and create lessons on standards not previously addressed. In completing this project, the ULS science department was able to contribute to the school's vision of preparing students for college, work, and responsible citizenship. It also fulfills the goals of our school-wide action plan to improve curricula by aligning courses with accepted national standards in order to achieve learner outcomes. The ULS science department is also providing the Hawaii Department of Education with a model for incorporating NGSS into science curricula.

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