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Arduinos and Games: K-12 Teachers Explore Computer Science (Evaluation)

Dr. Andrea Carneal Burrows, University of Wyoming

Dr. Andrea C. Burrows received a Curriculum and Instruction: Science Specialization research Ed.D. from the University of Cincinnati, M.S. in Science Education from Florida State University, and a B.S. in Science Education/Biology from the University of Central Florida. She is an assistant professor in the Department of Secondary Education at the University of Wyoming, where she teaches courses in science methods, pedagogy, and research. Dr. Burrows also creates, implements, and evaluates grants at UW. Her research interests include secondary STEM partnerships and the meanings, negotiations, and conceptual changes associated with partnerships. She publishes and writes about STEM education extensively.

Dr. Mike Borowczak, Erebus Labs

Mike is the chief scientist and founder of Erebus Labs - a Hardware Security and Engineering Outreach company located in Laramie, WY. He is also the Senior Data Scientist at a recently acquired startup. He has worked with university faculty to promote and extend K20 STEM outreach in Ohio, Oregon, Texas and Wyoming. He also has over a decade of industry and research experience - mostly revolving around the semiconductor and bio-informatics industries - with specific experience at Texas Instruments, Intel and Cincinnati Children's Hospital Medical Center. In addition to his industry experience, he has spent two years, while completing his PhD in Computer Science and Engineering, as a National Science Foundation GK-12 fellow - teaching and bring real-word STEM applications in two urban high schools. He has authored peer-reviewed articles, presented at national/international conferences, and taught undergraduate/graduate courses in both Hardware Security (computer science & engineering) as well as STEM Education and Outreach.

Arduinos and Games: K-12 Teachers Explore Computer Science

Abstract

A total group of 41 K-12 science, mathematics, and technology (STEM) in-service teachers chose to participate in a Math and Science Partnership grant for professional development (PD), named *Launching Astronomy: Standards and STEM Integration* or LASSI (resources found at UWpd.org/LASSI) for 25-days during the summer and academic year that involved astronomy and computer science (CS) opportunities (e.g. Arduinos) that they could recreate in their classrooms. Electrical/computer engineering, astronomy, and educational experts defined the activities, which were intended to introduce CS concepts to teachers and thus K-12 students in creative manners. The LASSI PD focused on astronomy – and used CS - as a vehicle to explicitly model problem-based learning, engineering design-based approaches, context-rich problem solving strategies, and real-world applications. All of the foci were ideally suited for helping K-12 students learn the interdisciplinary integrated STEM concepts now called for in the K-12 standards (e.g. Common Core and Next Generation Science Standards - NGSS). Although not traditionally used in STEM subjects (or explored in this paper), astronomy concepts such as black holes, distances to other stars, and planets in star systems beyond our own, are inspirational to K-12 students while being explainable at a technical and quantitative level. Quantitative assessment methods for the LASSI PD included an external evaluator who asked daily survey questions of the participants in the yearlong PD. Included in this paper are the results from 33 participants from two specific days (March and June 2015 respectively), where CS and engineering PD activities were explicitly targeted. Information about the two PD days and the five main PD activities are shared in the paper. Quantitative results show that the teacher participants gave the sessions a mean rating of 4.4 on a 5-point scale. All of the teachers reflected that they were engaged for more than 75% of the time, and at least 70% of all teachers reported that every activity was "very useful." The hands-on activities - implemented during the workshop -were rated by all teachers as "meaningful," and every teacher stated that they intended to use at least some of what they learned in their classrooms. The CS content and engineering learning of the teachers increased in pre/post test evaluation and was significant with a $p = .0000$, correlation of .14, paired-t test of 13.64, and effect size of 4.008. Qualitative K-12 teacher responses are shared in the paper to supplement the quantitative data.

K-12 Students, Teachers, and Computer Science

Teachers at all levels need to feel confident with the subject matter at hand in order to deliver strong science, technology, engineering, and mathematics (STEM) lessons[1,2]. As K-12 STEM standards expand[3] teachers require opportunities to engage with and internalize the content for creating robust STEM lessons. Professional development (PD) opportunities for both pre-service and in-service STEM teachers are crucial in involving teachers in experiences that develop their understanding and use of new STEM content. One area that is often unexplored is computer science (CS). Computer science and engineering are composed of many facets including computational biology, artificial intelligence, graphics, and computer architecture. Often, a general audience will respond that computer science focuses on coding, creating games, and/or fixing a computer, and unfortunately these are narrow views of computer science (instead of thinking of the logic involved). In creating a PD entitled *Launching Astronomy: Standards and*

STEM Integration (resources can be found on UWpd.org/LASSI), the authors examined hands-on learning laced with explicit discussion to change these misconceptions[4]. The LASSI PD focused on astronomy contexts – and used CS - as a vehicle to explicitly model problem-based learning, engineering design-based approaches, context-rich problem solving strategies, and real-world applications. All of the foci were ideally suited for helping K-12 teachers learn the interdisciplinary integrated STEM concepts now called for in the K-12 standards[3,5,7]. An illustration of the integrated STEM concepts are shown in Table 1, and the example showcases the STEM pieces.

Table 1: NGSS[3] integrated STEM example (Energy topic)

Students who demonstrate understanding can:

HS-PS3-1	**Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Create a computational model or simulation of a phenomenon, designed device, process, or system.	**PS3.A: Definitions of Energy** • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. **PS3.B: Conservation of Energy and Energy Transfer** • Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. • Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. • The availability of energy limits what can occur in any system.	**Systems and System Models** • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. - - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • Science assumes the universe is a vast single system in which basic laws are consistent.

Connections to other DCIs in this grade-band:
HS.PS1.B ; **HS.LS2.B** ; **HS.ESS2.A**

Articulation of DCIs across grade-bands:
MS.PS3.A ; **MS.PS3.B** ;**MS.ESS2.A**

Common Core State Standards Connections:

ELA/Literacy -

SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS3-1)*

Mathematics -

MP.2	Reason abstractly and quantitatively. (HS-PS3-1)
MP.4	Model with mathematics. (HS-PS3-1)
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS3-1)
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-1)
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-1)

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

Problem

STEM education is of utmost importance[6], highlighted by the standards initiatives such as the Common Core Mathematics[5], the NGSS or Next Generation Science Standards[3] and the ISTE or International Society for Technology in Education[7]. Engineering is a part of STEM, and as such "engineering as an iterative process that utilizes math tools and scientific knowledge to solve problems is reflected in various degrees throughout existing standards documents [throughout the U.S. states]"[8]. Accordingly, the NGSS standards[3] includes engineering practices. Thus, STEM content is currently ingrained in the U.S. K-12 educational system, but where does CS play into this K-12 picture?

It has been shown that CS is both an art and a science[9], and in January 2016 President Obama launched an initiative "to empower a generation of American students with the computer science skills they need to thrive in a digital economy"[10]. Research shows that up until this point a "programming-first" approach is used most often with K-12 students across the U.S.[11]. The authors of this paper argue that K-12 teachers who explore hands-on CS experiences are more inclined to engage their K-12 students in different uses of CS instead of relying only on coding[9]. Consequently, focusing on logic and algorithms (or process) rather than the end product of code (of any language) allows both K-12 teachers and students to make connections within STEM components.

As most K-12 teachers utilize the strengths of the students in their classrooms, (especially in relation to technology and computers) with further experiences the teachers will be inclined to use CS content that they know exists, even if they do not fully understand all of the aspects. Given the standards mentioned earlier, K-12 teachers need additional resources in order to provide CS opportunities for their students. For this study (situated within a larger PD context), the researchers investigated the question: *What CS learning gains and perceptions are shown in K-12 teachers exposed to two days of intensive, interactive CS activities in LASSI?*

Methodology, Methods, and Analysis

A total group of 41, elementary and secondary K-12 science, mathematics, and technology (STEM) in-service teachers chose to participate (thus self-selected) in the LASSI PD for up to 25-days during the summers of 2014 and 2015 that involved astronomy and CS activities (e.g. Arduinos) that they could recreate in their classrooms. All 25 days were structured to focus on STEM components with astronomy connections, however only two days of CS activities are highlighted in this study. Electrical/computer engineering, astronomy, and educational experts defined the activities, which were intended to introduce CS concepts to teachers (and thus eventually K-12 students) in creative manners. Thirty-three teachers took part in the two days that are examined in this paper (note that the two days examined here are purposefully chosen because of the number of CS experiences presented). In this paper the researchers examine CS learning gains and perspectives, not necessarily the astronomy connections.

The workshop provided opportunities for teachers to learn from one another and from experts in CS, engineering, astronomy, and education. The theoretical framework for this study was positivist in nature as quantitative data was the main source for the authors' findings. The

methods used to gather the data included: A) Likert scale perceptions survey of CS and engineering, and B) pre/post questionnaire regarding CS foundations including engineering. An external evaluator collected the quantitative data and the qualitative comments on the usefulness of the activities for K-12 classrooms and suggestions for improvement. These qualitative K-12 teacher responses are shared only as support of the quantitative data. The perceptions surveys were analyzed using the mean and distribution of responses. The pre/post content questionnaire results were computed using standard statistical analysis measures of mean, standard deviation, correlation, paired t-test, p (significance), and effect size. Qualitative responses were coded for teacher themes.

Overview for March 2015, *CS Day 1* – 11 people (subset of the whole group)
In late March, 11 teachers participated in an eight-hour day that included discussions and the following three main hands-on activities: 1) What is coding? The U.S. region game; 2) Computer science and NetLogo (via ccl.northwestern.edu/netlogo); and 3) Try-it stations with board games, Arduinos (via Arduino.cc), and more. These activities are described in the next sections.

1) What is coding? This game was a simulation of an algorithm in a computer, but the teachers did not know this before the game. The group of participants was given a stack of post-it notes with a city written on each one. Most of the cities were located in the U.S., but some were located elsewhere. The group needed to decide how to best sort the stack into geographical regions. The rules included that the teachers had an "input" person and a "output" person, but they could decide the configuration of the rest of the group. However, once the post-it started changing hands the teachers could not talk. There were several trials attempted, and eventually a group diamond shape emerged, and they could sort the stack of post-its (~50 cities) within a minute - without speaking. A discussion ensued about algorithms, efficiency, and optimization, and how these terms are related to what computers do and what coding is allowing astronomers and STEM specialists to do.

Teachers talk through the post-it note geography-sorting task before beginning another attempt.

Teachers try out their method of geography sorting that simulates a computer algorithm.

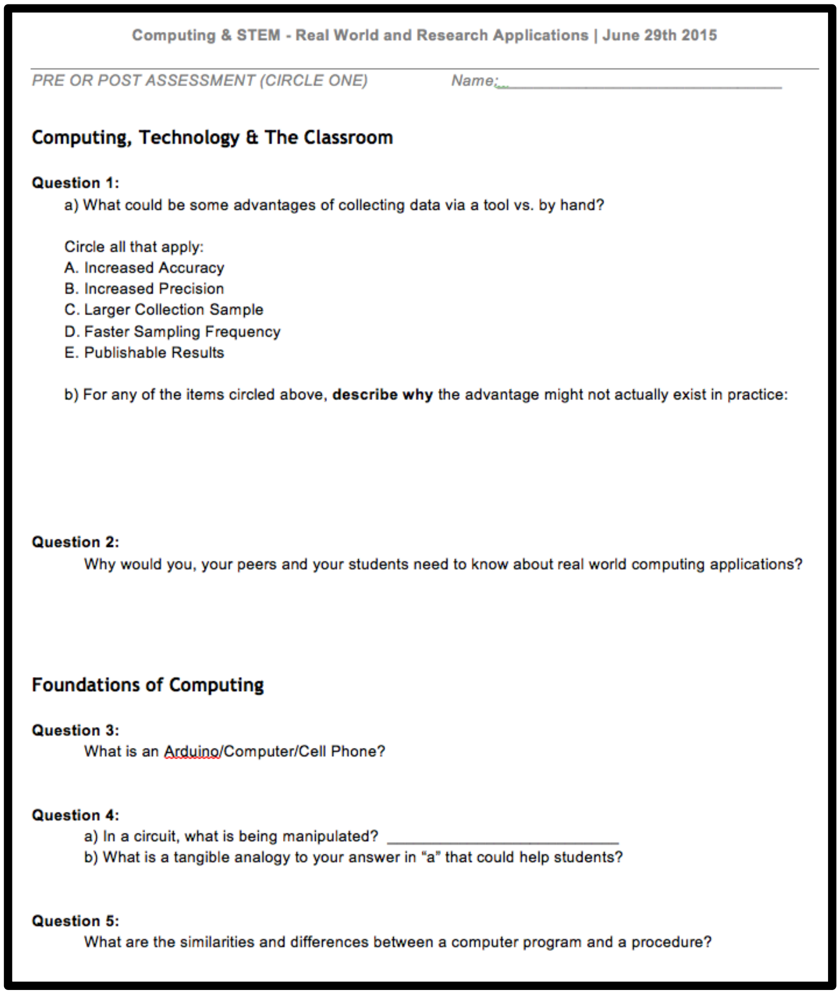
2) Computer science and Net-Logo (a simulation environment) showcased the large realm of STEM disciplines touched by CS and engineering. By using NetLogo, the teachers explored games (and ways to manipulate them) and thus CS. For example, they manipulated the food chain energy rule (biology), wildfire spread (ecology), molecules (chemistry), and orbiting bodies (physics/astronomy). Then the teachers discussed how the NGSS crosscutting concepts (see Table 2) were shown in each of the NetLogo interactive games.

Table 2: NGSS Crosscutting Concepts[3]

NGSS Crosscutting Concepts	Explanation
1. Patterns	Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. Cause and effect: Mechanism and explanation	Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
3. Scale, proportion, and quantity	In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. Systems and system models	Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. Energy and matter: Flows, cycles, and conservation	Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. Structure and function	The way in which an object or living thing is shaped and its substructure determine many of its properties & functions.
7. Stability and change	For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

3) Try-it stations included: A) Robot Turtles board game; B) Code Monkey Island board game; C) Arduinos (a programmable electronic device); D) Make: it Component Kits 1 & 2 that utilizes the Make: Electronics book; and E) Kahn Academy/Code Academy computer opportunities. The stations were open for exploration and the teachers could move in and out of the stations at will. One CS expert, one astronomy expert, and one education expert walked between the groups of teachers and questioned them regarding CS activity use in the classroom, and connections to CS, engineering, and astronomy. Explicitly connecting all of the activities back to astronomy and the methods in which the universe is explored was a purposeful daily discussion.

Overview for June 2015, *CS Day 2* – 22 people
In late June, 22 teachers participated in an eight-hour day that included discussions and the following two main hands-on activities: 1) Makey Makey[12] kits (via makeymakey.com); and 2) Try-it stations (extension from March). These two main activities are described later. For the quantitative survey a pre/post test content questionnaire regarding CS included questions relating to the foundations of computing (see Figure 1).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PRE OR POST ASSESSMENT (CIRCLE ONE) Name:______________________

Computing, Technology & The Classroom

Question 1:
a) What could be some advantages of collecting data via a tool vs. by hand?

Circle all that apply:
A. Increased Accuracy
B. Increased Precision
C. Larger Collection Sample
D. Faster Sampling Frequency
E. Publishable Results

b) For any of the items circled above, **describe why** the advantage might not actually exist in practice:

Question 2:
Why would you, your peers and your students need to know about real world computing applications?

Foundations of Computing

Question 3:
What is an Arduino/Computer/Cell Phone?

Question 4:
a) In a circuit, what is being manipulated? ______________________
b) What is a tangible analogy to your answer in "a" that could help students?

Question 5:
What are the similarities and differences between a computer program and a procedure?

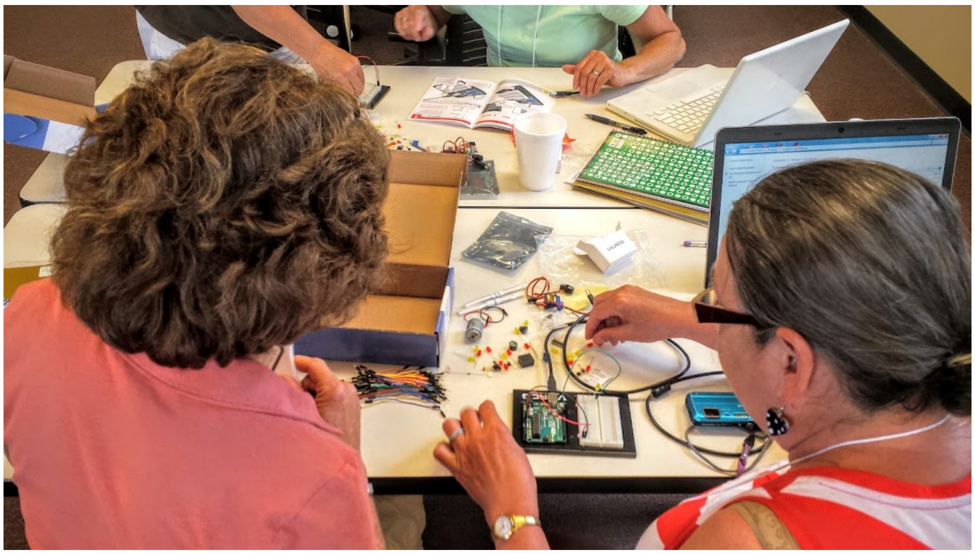
Figure 1: Computing and STEM – Real World Research Applications questionnaire.

1) Makey Makey[12] kits are "simple inventions kit[s] for beginners and experts doing art, engineering, and everything in between"[11]. The teachers explored these kits using fruit and play-doh as electricity conductors.

2) Try-it stations – extensions from March - included: A) Robot Turtles board game; B) Code Monkey Island board game; C) Arduinos; D) Make: it Component Kits 1 & 2 that utilizes the Make: Electronics book; and E) Kahn Academy/Code Academy computer experiences. Similarly set-up to the March PD, the stations were open for exploration and the teachers could move in and out of the stations at any time. One CS expert, one

astronomy expert, and one education expert walked between the groups of teachers and questioned them regarding activity use in the classroom, and connections to CS, engineering, and astronomy. Explicitly connecting all of the activities back to astronomy and the methods in which the data is explored was a purposeful daily discussion.

As noted earlier, astronomy connection discussions (e.g. Mapping out the sky, Processing the radio wave emission data, Identifying characteristics of quasars) were explicit at the end of the day's activities and related to CS and engineering. Qualitative comments were gathered from the external evaluator for support of the quantitative data.



Teachers work on building Arduino systems.

Findings

For the first CS LASSI PD day, the activity stations were successfully included in the March workshop, and the teachers' self-reported learning CS and engineering content as well as gaining confidence in CS use. Over half (n=6) of the 11 participants planned to incorporate the NetLogo simulations, and almost as many (n=5) identified the Robot Turtles board game and the *What is coding?* post-it activity as new ideas that they planned to use with their K-12 students. Those participants who offered explanations mentioned that these activities helped make lessons "more meaningful" for students by connecting ideas with games, engaging students "to visually see and experience" coding, helping them understand "how a computer works," and "how and why we would use code." Other individuals mentioned the Arduino station and Khan Academy as especially useful. The time spent collaborating on lesson planning was always useful, and all of the teachers reported the lesson planning time was extremely meaningful and productive.

Interestingly, each participant's suggestion for improving the March 2015 session was unique. Those comments that pertained to what happened during the session included: 1) adding an opportunity for participants to share their projects and hear what each had "learned/played with/could see themselves incorporating into the classroom;" 2) offering fewer activities and "having another computer science 'expert' on hand to help with coding questions when we are trying to make our own model/lesson;" 3) providing time to review the SparkFun[13] resources (via

SparkFun.com); and 4) increasing “exposure for coding as it relates to the development of apps for mobile devices.” Six participants said “Nothing” or offered a compliment and made no suggestions.

For the second CS LASSI PD day, the quantitative results show that the 22 teacher participants gave all of the sessions a mean rating of 4.4 on a 5-point scale. All of the teachers reflected that they were engaged for more than 75% of the time, and at least 70% of all teachers reported that every activity was “very useful.” The hands-on activities - implemented during the workshop - were rated by all teachers as “meaningful,” and every teacher stated that they intended to use at least some of what they learned in their classrooms. The CS content scores of the 20, K-12 teachers who took both the pre and post test, increased in pre/post test scores and were significant with a p = .0000, correlation of .14, paired-t test of 13.64, and effect size of 4.008. The effect size was large, and the large effect size is clearly evident in the charted distributions of pre/post total scores (Table 3).

Table 3: Quantitative teacher pre/post CS test results

June 29	**N**	**Mean**	**Std. Dev.**	**Correlation**	**Paired-t**	**p**	**Effect size**
Pretest	20	2.45	1.96	0.14	13.64	.0000	4.008 Large
Posttest	20	8.70	0.92				

Additionally, the teachers engaged with content regarding circuits and Kirchoff’s circuit laws, and increased their knowledge across a wide spectrum of astronomy and STEM topics. Specific topics addressed were angular size and distance and components of Arduino use, and the teachers discussed how to utilize the content and skills in their STEM lesson plans in the time set aside for collaboration. Teacher lesson plans and the activities that they participated in for all days of the LASSI PD are free and available online at UWpd.org/LASSI.

Limitations

This PD was conducted with only 33 teachers from one western, U.S. state, and the teachers’ K-12 student population was mostly homogeneous. There was a range of elementary and secondary teachers and the level of interest regarding some of the activities was skewed because either they were perceived as either too easy or too hard for the grade level of the teachers. The activities, when taken out of the whole PD context, lack some of the evaluation complexity as well as the astronomy connections, that are allowed when viewing all 25 PD days. The CS, astronomy, and education experts worked together before and after these LASSI PD sessions and as such have biases for incorporating those subjects’ content into discussions and explanations. Thus, some gains in teacher knowledge and confidence could be contributed to exposure to these subjects throughout the 25 days of the PD and other interactions with the experts. Lastly, follow-up with these LASSI teachers is needed to show sustained impact of LASSI.

Conclusions/Implications

Computer science and engineering can be included in K-12 STEM lessons, and astronomy can be a vehicle to entice and excite K-12 teachers and students with CS and engineering uses. Teachers can learn to value CS and engineering even if it isn’t the main discipline(s) that they

teach because of all of the rich connections of CS to other subjects. Chatting with experts, often informally, allows teachers the opportunity to "test the waters" of CS and engineering in a non-threatening manner. Likewise, using Arduinos, board games, computer simulations, and kinesthetic activities acknowledges that the teachers have some knowledge base about CS and engineering to build on in order to create engaging STEM lessons for their students. Allowing teachers the time to try-out CS and engineering content and skills in a safe-environment is crucial. Teachers need to experience failing and retrying tasks/skills in an iterative process like their students in order to structure lessons that are best suited to the STEM content that needs to be taught. Finally, the collaborative aspect of working together with peers and experts – exploring new frontiers - acknowledges that together teachers can achieve more for themselves and their students. Creating is often more vibrant in social settings and this was apparent in the content learning and perceptions of CS and engineering topics throughout the LASSI PD.

Future recommendations include that the creators of PD (such as the one described here), plan for and execute evaluations of K-12 student learning and growth as well as teacher interviews after these PDs are finished to further influence teacher practice – especially in regards to CS.

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