KALEIDOSCOPE:

KSTF
Knowles Science
Teaching Foundation

ABOUT KSTF

The Knowles Science Teaching Foundation (KSTF) was established by Janet H. and C. Harry Knowles in 1999 to increase the number of high quality high school science and mathematics teachers and ultimately, improve math and science education in the United States. KSTF operates three programs that build national capacity for improving STEM teaching, leading, and learning: Teaching Fellows, Senior Fellows, and Research & Evaluation. To date, KSTF has supported more than 250 Fellows in 42 states.

IN THIS ISSUE

WELCOME

Welcome to the Spring 2015 issue of *Kaleidoscope: Educator Voices and Perspectives.* We started this journal to share the knowledge and insight gained through our work in KSTF's unique professional network and to provide substantive and reflective writing informed by our classroom practices and our collaborative inquiry. The editorial board sees this journal as one way to inspire educators to reflect on their own practices, engage in dialogue with other teaching professionals, and play a role in transforming teaching and schooling practices.

We encourage readers to share this issue with teachers, students and anyone else who is interested in science and mathematics teaching and learning. If you have any comments or questions, please contact us at kstf.journal@kstf.org.

INTRODUCTION

The Spring 2015 issue of *Kaleidoscope* offers a diverse array of passionate teacher voices. In this issue, teachers' experiences and values take center stage; each author captures his/her beliefs around an aspect of being an educator.

Two articles center on the vital importance of schooling where the authors explore different versions of student voice. Senior Fellow Lindsey Quinlisk describes the struggles and joys of going to school in rural Tanzania through the eyes of Asinta, a representative high school student, and reminds us of the opportunities of education at home and abroad. Senior Fellow Lindsay Wells reflects upon her role as a mentor and advocate through imagining and writing about the "future lives" of her students.

Four Senior Fellows on the KSTF Engineering Task Force (ETF) present a multi-faceted view of the ETF's engineering design process through a discussion of the phases of engineering as related to science and math instruction. Casey O'Hara, Katey Shirey, Scott Murphy, and Kelsey Johnson take turns explaining and extolling the virtues of each design phase.

Two Senior Fellows discuss the importance of relationships and team communication to improve teaching and foster community. Carmen Davis reflects upon her move from a classroom teacher to a school-wide Director of Instruction and the epiphany that helped her transition. She challenges us to examine our collegial relationships as teachers intent upon equitable student experiences. Victor Chen shares the insights he gained from Critical Friends Group training and the impact of leading and participating in such a group on his local teacher community.

The KSTF Journal Editorial Board welcomes all feedback. Please email our editorial board at kstf.journal@kstf.org.

FUTURE STORIES

BY LINDSAY WELLS

Lindsay Wells
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Last winter, my husband and I realized that we would need to move out of Maine in order for him to find a job. For the remainder of the school year, I dreaded one specific moment above all others related to leaving my current teaching position. It was certainly unpleasant to consider sending in a letter of resignation, notifying my colleagues, cleaning out my classroom, and abandoning my curriculum works-in-progress. Yet none of these chores were what featured prominently in my anxiety dreams, or what worked itself into a tension knot in my neck.

For months, I obsessed about the first day of school when 15 sophomores would walk into my classroom after lunch and realize that I was no longer their teacher for the class that we call advocacy. This might sound narcissistic, but it's not because I thought I was irreplaceable. It was because I had made an unspoken agreement to stick with these students through all four years of high school. When that first-day moment came, they would realize I had broken my promise and abandoned the team.

To back up for a moment, when my husband and I moved to Maine a little over a year ago, we fully intended to stay there for at least five years, if not longer. I started teaching at a small, rural high school north of Portland last fall and enthusiastically began the long journey toward becoming part of the community. I begged my principal to let me have a freshman advocacy group rather than lunch duty, because I had *ideas* for what I could do with a small cohort of ninth graders that I would see for thirty minutes after lunch every day until they graduated.

The advocacy program has been many things in the years since its inception, but the current incarnation consists of four weekdays of silent reading (students are supposed to bring in reading material of their choice) and one day of "not reading." The agenda on non-reading Wednesdays is mostly left up to each advocacy teacher, although sometimes there's a school-wide activity—a class meeting, a speaker, a fun challenge posed by some club or organization. Students around the school often referred to this as their "free day," but my group quickly learned that it was, in fact, a "whatever-Ms.-Wells-decides-we-are-doing" day. My plan was to use all four years to build my advocacy students' motivation and capacity for engaging in service projects to address important issues of their choosing. This is something I have always wanted to be able to do, and the half hour of "whatever" time mid-week seemed like a golden opportunity.

I need to say a few more things about why my advocacy students were so important to me before discussing what I did about that

dreaded *moment*. First, other freshman advocacy teachers sometimes joked that I had a "stacked" group. I'll admit that I did have some pretty top-notch kids, but I also had several who seemed stuck at the bottom of the academic and/or social ladder. I know this because as the only ninth grade physical science teacher, I taught all 120 students in the freshman class. I can assure you, my advocacy was as much of a random cross section of the grade as anyone else's. However, at the beginning of the year I started a campaign to convince my students that they were, in fact, the best group. After a while this idea stuck, and it ultimately started to become a self-fulfilling prophecy.

Whenever my students asked why I was making them do something different than the other advocacies—such as team building activities, listening to podcasts and discussing social issues, or brainstorming how to remedy negative aspects of the school culture—my reply was always along the lines of, "because our advocacy is special and we have to set an example for the others." I even made a big show of ushering out students from other groups who tried to sneak into my room just before advocacy on a regular basis.

With this attitude, it was no surprise that we won the freshman kickball tournament in the spring. In addition, it didn't take much effort to persuade my students to help develop and then participate in a goofy social experiment at the end of the year about the transformative power of kind acts. Yet, while I think I successfully convinced my advocacy that they were the best group, my job was not done. By the end of their senior year, I had hoped to convince every student that each one of them, individually, was someone whose actions made a difference, and that they could make choices worthy of admiration and emulation. Now that I was leaving, how on earth was I supposed to condense three years of intended support and encouragement into just a few words that could be delivered on that first day of the new school year?

Also, why did I care so much? Reflecting upon why I was so emotionally invested in this small group, I realized that the opportunity to help students develop into leaders is one of the main things that motivates me (and many others) to teach. I firmly believe that teachers have the power to alter students' self-perceptions in ways that can influence their future

choices and perhaps even their destinies. A recent New York Times article captured this sentiment when explaining why efforts to turn teaching into a business have been so unsuccessful (Kirp, 2014):

> *"All youngsters need to believe that they have a stake in the future, a goal worth striving for, if they're going to make it in school. They need a champion, someone who believes in them, and that's where teachers enter the picture. The most effective approaches foster bonds of caring between teachers and their students."*

At the beginning of the year I started a campaign to convince my students that they were, in fact, the best group. After a while this idea stuck, and it ultimately started to become a self-fulfilling prophecy.

In the classroom, the message, "I care about you and believe in your future," often gets lost in the zillion other things we need to communicate to our students. On the other hand, advocacy was a time and place free of academic expectations (at least on Wednesdays), and as a result, I enjoyed the ability to cultivate stronger relationships with those students.

As for what to do about that dreaded first-day moment, my initial thought was to write each student a letter detailing their best qualities. Yet, when I sat down to write, something completely different came out: a series of what I'm calling "future stories."

Each student's story was a quirky, second-person narrative of a day in their senior year. Some were set in the beginning of the year, some in the middle, and a few at the end. All of the stories had several elements in common: everyone had a leadership position at school or in the community; they had gotten their grades to the point where they had several options for college; their stories intersected with those of other students in my advocacy; and

they had accomplished something heroic or unusual for a high school student. Here's an example of my story for Sarah[1], a girl who rarely completed school work and was frequently on the in-school suspension list:

By the end of their senior year, I had hoped to convince every student that each one of them, individually, was someone whose actions made a difference, and that they could make choices worthy of admiration and emulation.

SARAH IN 12TH GRADE

Passing the in-school suspension room today on your way to the gym, you think "wow, it's been a long time since I've seen the inside of that door!" You've got your yoga mat under your arm and are considering what to do if too many people show up to the class you're teaching this period. Maybe it's time to offer a second class in the evenings? You think back to your sophomore year when you discovered that yoga and meditation really helped to tune out all the crazy things that were happening in life outside of school, and as a result, you were able to concentrate more on your classes and stay out of the office. At the end of the year, you suggested to Mr. Gibson [the principal] that other students might benefit from this as well, and surprisingly, he agreed. After getting a scholarship to attend a summer yoga workshop, you started leading a class for all the kids who everyone thought would never be interested in anything other than getting in trouble, and it was a huge success! Last spring, some girls on the softball

[1] All names are pseudonyms

team started coming to your class, and now a bunch of other athletes want to join (which is why it's getting so crowded). Lately, you've also been thinking about what to do after graduation. On the one hand, your grades are good enough to get into college now, but on the other hand, you know you could make a lot of money if you went to work full time on the clothing design business that you and Heather started. This will be a tough decision...

Sarah's yoga class was featured in two other students' stories. A girl on the softball team credits it for helping her recover from an injury and a boy on the football team notes how professional and encouraging she is as a teacher. In my mind, I pictured students reading their stories and then discussing all the surprising things that "happened" to them, and how their lives overlapped:

"Hey, who else went on the trip to Kenya?"
"I did...it says I organized it because I'm the president of the International Club."
"I went too! It made me want to become a doctor."
"Ryan—you're in my play!"
"Did we all attend Jill and Kevin's environmental rally in Portland?"
"Yeah, I think so. I only went because I owed Jill a favor. She sent my screenplay to someone she knows in Hollywood."
"Apparently, I also saved someone's life."
"Does anyone know if we finished the robots we were building?"
"Melanie, what's Peer Mentoring and why have we been traveling around the state talking to people about it?"
"Hey, I'm a Peer Mentor too! I also opened a school store!"

At first, I had no idea where these stories came from. Later, I realized that they stemmed from what is likely a common teacher experience. To some degree, we all must envision a brighter future for our students than they see for themselves in order to stick with the profession. The countless hours we spend mentoring, tutoring, and encouraging our students (on top of teaching them content) only seem worthwhile if we can picture our students as future leaders, change-makers, good parents, and engaged fellow citizens. It is the vision of them living up to their most positive potential—and the world this would create—that keeps us in the game.

To some degree, we all must envision a brighter future for our students than they see for themselves in order to stick with the profession.

Having worked in several different schools, I've noticed that each student population has its own unique set of challenges. During my interview for the position at the school in this article (which serves a small rural community), I asked what difficulties students typically face. One person said that students' main challenge is that they don't dream very big. They are too often content with mediocre grades—as long as they're passing, or eligible to play sports—and typically stay close to home after graduation, even if they have the opportunity to go much farther. Initially I didn't think this was such a big deal, especially after having taught in an urban setting where students struggle with more immediate and tangible problems like poverty, violence and teen pregnancy. However, I now see how low academic expectations of any kind—whether they're a result of an unsafe or simply an undemanding school culture —are detrimental to students' futures.

My final thoughts for the reader are as follows. Can you recall a moment when the vision you had for your own future expanded? Who or what inspired you to think bigger? What happened as a result? What are the elements of *your* future story for your children, the kids next door, downtown, across the country, and around the world?

REFERENCE
Kirp, D. (2014). Teaching is not a business. The *New York Times*. Retrieved from www.nytimes.com. August 16, 2014.

TUNAENDA SHULENI!
WE ARE GOING TO SCHOOL!

BY LINDSEY QUINLISK

Lindsey Quinlisk
is a KSTF Senior Fellow who taught math in Colorado. Before becoming a teacher she studied engineering with a civil specialty at the Colorado School of Mines. During the 2013–2014 school year, she taught at a rural school in Tanzania.

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Photo by Lindsey Quinlisk

Girls playing netball.

INTRODUCTION

I spent ten months in the rural village of Lyapona in Tanzania, East Africa. I was teaching English and mathematics to Forms one, two and three (9th, 10th and 11th grade). I wanted to share my experience but have decided to do it from a student's perspective. As teachers, we can get so focused on curriculum, assessment, and policy that it is easy to forget to see things from a student's eyes, whether in America or Tanzania. This story is told by a fictional student named Asinta, who is a composite of the lives and stories of my actual students. Imagine yourself sitting on a short wooden stool, next to a charcoal fire in a mud brick house with tin roofing, and open your mind and heart to what Asinta has to say.

If I weren't going to school, I would be digging in the dirt. I would be a farmer, married and most likely pregnant by now. As a 19-year-old girl living in rural Tanzania in East Africa, that is the expected life story. That was my mother's story, my grandmother's story, and my great grandmother's story. But it's not going to be my story. I am among the growing number of girls who are breaking out of the mold by going to secondary school. And I am incredibly proud of it, though it hasn't been easy.

"Hey, remember that day when we were carrying bricks for building the classroom and the snake crawled over Secy's foot, and she jumped so high her head hit the tree?" Juma's voice catches my attention. Godfrey and Charles are doubled over with laughter while Secy glares at Juma for bringing up that embarrassing moment. We are all sweeping the main grounds of the school with our brooms that we made by picking grasses and twigs. It is our morning routine to sweep after the 7:15 a.m. attendance call. I don't remember that incident because I wasn't there. The four of them are natives of this village while I come from one four hours away. They were a part of the group of students, parents and grandparents from Lyapona, the local village, who built this school three years ago. Before that, there was no secondary school here ever.

Zilpa, the student timekeeper, rings the bell at 7:30 a.m. for the morning speeches. All 98 of us students gather on the main assembly ground, looking unified in our white collared shirts, blue sweaters, maroon skirts or pants, and black shoes. Beyond our school uniforms, we are unified in another aspect. We didn't make it into the government-run secondary school. The Tanzanian government

simply doesn't have enough money to send all children to secondary school. Only the top 12% of students who finish primary school are eligible to attend the government-run secondary schools. All of us were in the other 88% that were told our school careers would end at seventh grade. And so it would be, if it weren't for Village Schools Tanzania (VST), that believes that every child, no matter how poor or of what background, should be able to go to secondary school. People like Charles' and Juma's parents heard about Village Schools and asked for a school in Lyapona. VST agreed, saying that if the villagers build the schools, then they will bring the teachers and the books.

"Eliza, you're next," Ibrahim, the head academic student calls out. I shoot my best friend a look of sympathy. We all dread getting picked for morning speeches, well except for boys like Musa and Evarist, who speak English really well. It is bad enough standing up in front of the rest of our classmates and having to make a speech, but now we have to do it in English, our third language. I grew up speaking Fipa, my tribal language, but started learning Swahili, the national Tanzanian language, in primary school. Now that we are in secondary school, we have to study English, the other national language of Tanzania. And it's HARD! All of our classes like biology, geography and mathematics are in English. Many times, on the tests, it is not the question itself that stumps me, it is reading the questions in English and understanding what it is asking. Either that or finding the right words to answer it in English.

"The factors that led to the decline of the trans-Saharan trade include the opening of new trade routes from Europe to West Africa, the construction of railways into the interior, and the increasing dangers of crossing the Sahara." I smile at Eliza to encourage her. She always amazes me with her ability to remember these topics that she studied three years ago in form one (9th grade). I don't like history and always struggle on the tests, but Eliza has an incredible capacity to remember these facts, in English, nonetheless. Eliza's grandpa doesn't believe that girls should go to school. He told her parents that Eliza must stay home and get married like a proper girl. But her parents, especially her mother, insisted on Eliza going to school. Eliza is glad that they sent her, even if it means her grandpa won't talk to them anymore. She's the top student in form three

(11th grade), getting the highest average score on all the subject tests last quarter. Who says that girls aren't good at academics? Eliza definitely is!

Zilpa rings the bell at 8:00, the start of classes. I head to the classroom with the other 25 students in form three. We stay in the same classroom all day while the teachers come to this room when it is the period to teach their respective subjects.

"Asinta, no matter what, I don't want you to give up! You must keep going to school. Your father and I never got to go to secondary school, but we want all of our kids not only to go but to graduate secondary school. You must keep going to school!

"Alright class, let's discuss that group problem of circuits with parallel resistors. What solutions did you come up with?" Teacher Mathias is my favorite teacher, and I really enjoy his physics class. He does a great job of explaining concepts both in Swahili and in English and he is always checking in to make sure we really understand. For those who don't understand, he will bring them in small groups to work with him in his office. Other teachers just come in, give a lecture, leave without really explaining anything, and then yell at us when we fail the test. Not Teacher Mathias though, he really cares, and he encourages us to work together. Even Miriam, who absolutely detests math and science, has done much better on her tests since Teacher Mathias came. He really wants us to be ready for the national exam and has the goal that we will have the highest scores in our entire region.

The national exam is difficult. I should know because I took it already and failed. Well, only the form four exam. I have passed the form two exam twice, and I am really proud of that. You see, we have to take a national exam in form two (10th grade) and in form
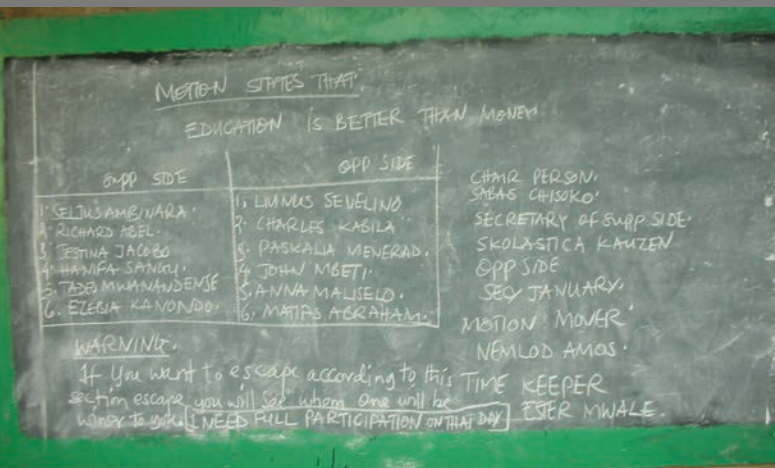
Photo by Lindsey Quinlisk

Every Wednesday, students have a debate to practice their English skills. This week' topic: Education is better than money.

four (12th grade). The form two exam covers all topics in form one and form two. If you pass the form two exam, then you can go on to form three. If you don't pass then you have to start over in form one. I passed form two, then did form three and form four, and then failed the form four national exam, the one that allows me to graduate secondary school. The form four exam covers all subjects from form one through form four; there's a lot to remember!

Mama sat with me the day we found out I failed the form four exam. "Asinta, no matter what, I don't want you to give up! You must keep going to school. Your father and I never got to go to secondary school, but we want all of our kids not only to go but to graduate secondary school. You must keep going to school! That way you can become a nurse, a teacher, a policewoman, something other than a farmer."

"Mama, you know I love school but it is hard to study here. I come home from school and right away Pascal needs his diaper changed, Shose needs me to help her with her math homework, and there's water to fetch, clothes to wash, and ugali to cook. By the time I sit down to work on my own homework, it's late, and I am so tired I end up just falling asleep instead of studying."

That was the day that Mama told Father that I must leave our village and go to school in Lyapona. Father was reluctant but he saw the wisdom in it. If I was going to graduate secondary school, I needed to be away from the demands of helping out at home

and on the farm and be where I could focus just on my studies. It was a big sacrifice for them to send me. Not only because as the oldest child, I would no longer be there to help Mama with all the household chores and taking care of my six younger siblings, but the school fees would be twice as much and they would have to pay for a room for me to live in Lyapona. So that's how I ended up at going to school in Lyapona. I had to start in form two again, take the national form two exam again, and now I am in form three. Next year I will be in form four and aiming not only to pass the national exam but get the top score in our school. That way I can show my parents that they made the right decision by keeping me in school and not marrying me to Uled, who offered my parents the bride price for me to marry him.

Today we have physics for 80 minutes, then English for 80 minutes, then civics for 40 minutes before the 11:20 a.m. break. During the break, we all head to the peanut farm behind the school. Mama Adelah and her family have finished harvesting so whatever peanuts are left on the plants and ground is up for grabs. We stuff as many as we can into our mouths and pockets before the bell rings for the 11:40 a.m. class. Now we will have Swahili for 80 minutes and then geography for 80 minutes.

"Hey Asinta, what did you get for that logarithm problem?" Isaya asks me. Teacher Hassan, our Swahili teacher, isn't here yet; he is late for class as usual. But that's OK because we usually spend any time we have no teacher working on homework assignments. "I got log 12. What did you get Isaya?" I like working with Isaya. He is a lot older than the rest of us. He is 39, married with two kids and another on the way. He owns the tiny pharmacy in the village but he comes to school everyday because he only finished seventh grade. He did go through a two-month training program to be certified to open his pharmacy but he is so curious and wants to know more, and that is why he is here studying with the rest of us 16 and 17 year olds.

At 2:40 p.m. the final bell rings, and we head out to the assembly grounds for announcements before going home. As soon as the teacher lets us go, we all take off running to the village, shortening the 25 minute walk.

"Tag, you're it!" Eliza tags me. I dash after Matha, my other roommate and as I catch her, I say, "Tag you're it, and it's your turn to fetch water!"

"Yeah, well it's your turn to cook today," she retorts. "Ok, that means that Eliza has to go to the market and buy greens!"

At our rented room, the three of us change out of our clothes and go our separate ways to get the chores done. I grab some charcoal and get the fire started and water boiling to make ugali, a cornmeal mush that we eat with our hands and use to scoop other food. Today we will have beans and cooked greens.

I hear the students greeting the elders in the village as they pass by our room, the cue that it is time to go back for evening session. Every day except Sunday we go back to school in the evening from 4:30 p.m. to 6:30 p.m. and depending on the day of the week, we do something like clean the classrooms, have debate in English, or personal study time. Today is my favorite: sports and games. The boys play soccer and the girls play netball (like basketball but different rules). I am really good at netball, so good that I am the captain.

Today, I rally the girls in a circle to do our passing drill. "Remember Emma to always have one foot on the ground!" I call out. "Esta, you can catch with two hands but only throw with one!" As the girls toss the netball to each other, I pause and marvel. It really is an incredible gift that each of us are here at school. I look around—Wini, Matrida, Jestina, and all my other sisters here have a different story. Each story is filled with sacrifice and challenges and countless reasons why we should have stayed at home instead. But here we are, sharing the same story of studying in secondary school. Now each of us will be rewriting our daughters' story, our granddaughters' story, and our great granddaughters' story—that one day, every single girl in Tanzania will go to secondary school.

Afterward: Honestly I have come back with way more questions than clear answers for my own teaching practice. One of my takeaways is that despite the poverty and the challenges the students face, the Tanzanian education system is highly rigorous, in some ways more rigorous than in the U.S. We should not let students' stories, many of which reveal hardships and challenges, tempt us to go easy on them.

Likewise, giving students more "adult" responsibility can better equip them for the future. Tanzanian

students are the custodians, secretarial staff, time keepers, coaches, and counselors for their schools. In short, they are getting more "real-life" leadership experience than some American student leaders who are planning the homecoming week activities and the location for prom.

My hope is that by sharing Asinta's "story," it is a reminder that education truly is a gift and an incredible privilege. However, her story is not exclusive to Tanzania. Many of our own students in America face daily challenges coming to school, and as teachers, we can benefit from taking the chance to hear some of their stories.

Lastly, there are some instructional strategies where simple is better. My only teaching tools were chalk, the blackboard, and the students themselves.

Obviously, every school structure is different but it does make me wonder how I can foster authentic student leadership and responsibility within my classroom as well as in our school and community. My hope is that by sharing Asinta's "story," it is a reminder that education truly is a gift and an incredible privilege. However, her story is not exclusive to Tanzania. Many of our own students in America face daily challenges coming to school, and as teachers, we can benefit from taking the chance to hear some of their stories. Feel free to share this story with your students and other colleagues as a starting point.

CITATION
Quinlisk, L. (2015). Tunaenda shuleni! We are going to school. *Kaleidoscope: Educator Voices and Perspectives, 1*(2), pages 7-10.

STEPPING OUTSIDE THE FOUR WALLS OF MY CLASSROOM: STEPPING OUTSIDE OF MYSELF AND MY UNWARRANTED LABELS

BY CARMEN DAVIS

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I recently made the transition from being a teacher to a school administrator. Many would call this move "leaving the classroom;" however, I like to think that I stepped out of my classroom long before I got this new role. For me, I "left the classroom" the moment I realized I was only as good as the team that I was a part of. When you begin to be concerned about the growth, development, and success of students and staff members outside of your four walls, you have mentally shifted the focus off just your classroom.

Unfortunately, I didn't always have this mindset. Like many teachers, I spent my first few years on my own island, locked in my own classroom, only concerned about my survival and the experience of my students. When the waters got shaky, I spent a lot of energy trying to save myself instead of seeking the help of those around me. In fact, I didn't think those around me had much to offer (yikes). I was relatively successful based on student feedback, student test scores, and my administrator's evaluation of my teaching, so it was difficult to convince myself that I needed to step outside of room 208 for anything. However, the turning point came when I realized that even within my school, there were many inequities. I could give students the best experience in my classroom, but what happened after they left my class? How was my school ever going to be successful if all of the adults had a selfish perspective narrowly focused on their own classroom and practice?

These lingering questions inspired me to pursue forms of teacher leadership in order to have access to "fixing" teachers around me, so that all of our students could experience academic success, no matter what class and teacher they were assigned (yes, I am aware of how obnoxious and pompous this sounds, but stick with me). However, becoming a teacher leader and stepping outside of my classroom to reach others ultimately had quite the reverse effect; I began to have an identity crisis when my examination of others started to become more about *me* and *my role* in our dysfunctional relationships.

I now believe that if we are to truly become effective educators and school leaders we have to begin by examining our relationships in order to understand our ever-changing identity in this work.

Take a moment to think about your relationships with people at your school. Do you believe that these relationships impact your development as an educator and therefore your impact on students,

or do you believe that you have sole control over your identity and development?

EARLY ASSUMPTIONS ABOUT MY ROLE AS A TEACHER LEADER

I approached my formal teacher leadership role with a sense of urgency and a fix-it mentality. I selected the content for department meetings, set the agendas, and facilitated based on what I thought were the needs of the group. Two years into my journey to "fix" others, I still felt like I hadn't accomplished much; I still felt like my department was stuck in a place where complacency and mediocrity were acceptable. I was frustrated and disappointed with the lack of movement and growth. I was frustrated because our students were still not receiving an equitable education even within our department.

I went back and forth about whose fault it was that we were not making progress as a group in moving towards a place of authentic learning and inquiry. At times, I put all the pressure on myself as the facilitator and then later put the pressure back on the group. However, what is interesting is that I never thought of myself as a member of this group. In other words, I never saw myself responsible as a participating group member. It was either all of my responsibility as the leader or their responsibility as the group. This epiphany became the turning point in my inquiry. How could I ever expect to make true progress if I didn't even feel truly connected to the group? What were the barriers preventing us from truly connecting?

THE IMPORTANCE OF RELATIONSHIPS

Teaching is relational; you can't be successful in this craft unless you have positive relationships with your students and colleagues. However, simply having a relationship does not guarantee success, as the type of relationship is key. There are three types of positive working relationships that I have experienced as an educator: congenial, collegial, and collaborative. While each relationship type has offered me something positive and influenced who I am as a character in this work, not all have helped to sustain my love and commitment to the profession or helped me to grow as an educator.

Many of my relationships with colleagues over the years have started and somehow gotten stuck on the congenial surface level. We are able to chat about personal matters, vent when things are going wrong, celebrate life milestones together, and share a drink at happy hour on Fridays, but when it comes to developing and challenging one another in order to become better educators, we seem to lack the capacity or perhaps interest.

Teaching is relational; you can't be successful in this craft unless you have positive relationships with your students and colleagues.

While most of my relationships with colleagues are congenial, there are a few that have managed to move beyond the basic social interaction level into a place where we can share our experiences with instructional practices. For me, the collegial type of relationship is more heart-wrenching than the small talk relationships, because we are playing the middle ground and stuck in the "land of nice." Yes, we are actually talking about what matters most, our teaching, but we are not having a real conversation. In the "land of nice," we share things about our teaching, with the purpose of *providing* information, not *seeking* information or feedback.

I struggled to get unstuck from the mud in the "land of nice," because my prodding might have been perceived as an attack instead of an invitation to inquire into practice. So instead of being misunderstood and disrupting the comfortable nice atmosphere, I just nodded my head and moved on. As a result, I was always left alone to think about the places I wish I would have taken the conversation and the potential for relationships. I was often upset with my cowardice in these situations, especially because I knew that asking one thoughtful question could positively influence a student's experience in a class and similarly, not asking that question could have the adverse effect.

After taking stock of my own relationships, I realized that I wanted something for everyone else that I had not experienced myself. I wanted authentic collaborative relationships. It was during this time that I began thinking about the dynamics of well functioning and effective working relationships. The elements that came up over and over again were: respect, trust, risk-taking, vulnerability, the capacity to get better, and a desire to grow.

How could I ever expect to make true progress within the group if I didn't even feel truly connected to anyone in the group? The new lingering question became why did I not feel connected to them if I genuinely liked them as people?

While discussing my inquiry with fellow KSTF PING (Practitioner Inquiry for the Next Generation[1]) members, I realized some painful truths about my perception of my colleagues. I really didn't see them as learners, and I didn't value them intellectually. This was a shocking and shameful realization because it was the antithesis of how I approached working with my students. Instead of being patient and contributing to their development, I was unknowingly judgmental, and this prevented me from truly connecting and collaborating for the common good of our school community.

How could I ever develop an authentic learning space with people that I didn't believe had anything to offer me, and why did I feel this way is the first place? Who did I think that I was?

LESS ABOUT THEM, MORE ABOUT ME
In order to answer this question, I had to unpeel layers of my own identity and engage in some self-reflection. How did others perceive me? How did I perceive myself? Where were the intersections of these perceptions?

Being labeled as a teacher leader brought along many perceptions and misconceptions that unknowingly became a part of my daily existence as a teacher. The mere fact that an administrator put me in the position implied that I had something other teachers in my department didn't, that perhaps on a spectrum of being "all set" to "needing to be fixed the most," I felt much closer to being "all set." Sure, I had my issues, but those were relative when compared to my colleagues', right?

I wanted to explore the possibilities that existed outside of the lines that my colleagues and I had placed around each other. What would it take to flatten the hierarchies that existed in our school community? What could be accomplished if every educator felt empowered?

While I have not found an answer to all of the questions I have posed, I have begun to discover more about myself and the power of collective ownership of student learning through one relationship with a colleague.

A PROMISING RELATIONSHIP
Chris[2] and I began teaching the same year and our relationship started, as most of my colleague relationships do, with small talk, and it eventually progressed to the next level when we joined the same grade level team. I don't remember when or how it exactly happened, but at some point I realized that I felt comfortable being my complete, unfiltered self around him. I remember thinking, "...wow I can actually share my true feelings, struggles, and questions with him without feeling judged, and in addition, I actually believed that he has something to offer me in return."

Although I don't remember the details of this transition in our work relationship, I know that I only felt comfortable after Chris began to show me how "real" he was. Real in the sense that although he was lauded as a great teacher among students and other colleagues, he was OK with showing me his vulnerable side by asking me questions and asking for my input on solving problems related to his practice. Although we taught in different content areas, he was the one colleague I approached whenever I needed a thinking partner about classroom management or learning activities I wanted to try. He pushed my thinking and

challenged me to grow in ways that I never thought possible. He forced me to re-define professionalism and professional relationships. We have grown as teachers, leaders, and as true friends because of the collaborative nature of our relationship. We trust each other to be real, take risks, ask for help, but most of all to learn and inquire into our practices together for the betterment of our students.

The progression of this relationship gives me hope for how other relationships have the potential to become more collaborative. However, what I have learned most from the relationship I have with Chris is that it takes one person to be brave and show their vulnerabilities. Typically, I am the person that needs to see this quality first in someone before I offer the same in return. This need makes me wonder how many of my colleagues are waiting on me to be brave. How many relationships have I kept stuck because of this need?

The bigger issue that spans far beyond my story and journey is that we can't afford to have students fall through the cracks because we won't talk to each other about the real issues in our practice that affect student learning.

BE BRAVE!

I have to learn to be brave, not because I am the designated leader in a group, but because I desire more from my work relationships in order to impact what is happening to the children we are all responsible for educating. I need to be brave for my students. I need to show more vulnerability for my students. I need to ask more probing questions for my students. I need to move relationships forward for the sake of my students... If for no one else, but my students.

What's your story? Who is waiting for you to be brave? Who needs you to step outside of your classroom?

The bigger issue that spans far beyond my story and journey is that we can't afford to have students fall through the cracks because we won't talk to each other about the real issues in our practice that affect student learning. We can't afford to have young people fall through the cracks because we are only selfishly concerned about what happens in our own classrooms. It takes one brave person to step outside their classroom. It takes one brave person in a relationship to push it to the next level. Will it be you?

REFERENCE

Cochran-Smith, M. & Lytle, S. (2009). *Inquiry as stance: Practitioner inquiry for the next generation.* New York: Teachers College Press.

CITATION

BRINGING A SLICE OF KSTF TO MY SCHOOL: HOW STARTING CRITICAL FRIENDS GROUPS HAS HELPED CREATE A SPACE FOR PROFESSIONAL REFLECTION AND DISCUSSION

BY VICTOR CHEN

Victor Chen
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As I dreaded graduating from my five-year Fellowship with the Knowles Science Teaching Foundation (KSTF), the question I found myself faced with most was "how can I bring the culture of KSTF to my school?" I really appreciate the working relationships I have built with my colleagues within my school over the past years. However, one of the things I valued most about being in KSTF was the quality of thinking and reflecting I had when talking with Fellows. While I've had instances of such in-depth conversations in my school, I desired these types of conversations to be the norm rather than the exception.

I teach in an urban high school near Detroit with a population of about 1,000 students. Around 73% of our students are Black, 23% are White, and 65% of all students are considered economically disadvantaged (free/reduced lunch). Many of our teachers, including me, commute in to our school and come from very different backgrounds from our students. Our staff cares a great deal for our students, but we have had few professional opportunities to reflect on our practice since much of our professional development time has been spent looking for ways to raise test scores.

To shift my staff's mindset about professional reflection and discussion, I decided to attend a Critical Friends Group (CFG) workshop. According to the National School Reform Faculty (NSRF), "CFG™ communities consist of 5-12 members who commit to improving their practice through collaborative learning and structured interactions (protocols)." Here, members work on things such as reflecting on their practice, critically solving problems, building trust with one another, and developing solutions to complex dilemmas.

Before I continue with my story of bringing CFGs into my school, I want to elaborate on the term "Critical Friends." I think Deb Bambino states it best when she says the work is "critical" because it "challenges educators to improve their teaching practice and to bring about the changes that schools need" without being negative or threatening, and the work involves "friends" because they "share a mission, offer strong support, and nurture a community of learners" (2002, p. 27).

From attending my CFG coaching training, I came away with three big ideas for creating a more professional atmosphere: building trust; keeping things relevant; and facilitating a professional discussion.

The first idea on building trust was something I never considered previously. Fellows at KSTF have an inherent trust among themselves, because we all want to grow professionally and want to help our students as best we can. By spending valuable hours together at our meetings and online through discussions, we learn about each other and learn to trust one another more and more.

In my school, trust between colleagues is generally easier to form within departments; however, there is far less interaction between individuals from opposite sides of the building. Since CFGs are designed to promote collaboration between colleagues of all teaching disciplines, I knew that I had to gain the trust of others to show that what we were trying to accomplish with CFGs was going to be relevant and meaningful to our professional careers and not just be another fad in education reform.

The second big idea from my coaching training was the idea of talking about something relevant and important during a meeting. While most meetings I've been to have an agenda, not every item on every agenda was meaningful for me. As a result, I admit that I did not put forth my best effort when topics were less meaningful.

To prepare for our CFG training, our coaches had us each bring four pieces of evidence: student work and learning data that was puzzling or raised concern; a lesson from our practice that needed to be revised; a critical incident from our practice that we had not been able to get out of our minds; and a dilemma from our practice that raised questions and caused tension. Throughout the week, attendees of the CFG training practiced facilitating protocols that addressed these topics, but because these topics were created by us and were meaningful to us, we all knew that each conversation was important and relevant.

Finally, the third big idea from my training was how important it was to properly facilitate a professional discussion around the topic of interest. In attending many meetings in the past, one of my constant frustrations has been a lack of direction by the meeting facilitator. For instance, if a topic such as "low test grades...what can we do about them?" shows up on the agenda, people at the meeting might talk for an hour or more without accomplishing anything.

Rather than simply opening a topic up for conversation, CFGs use a protocol that is chosen by the facilitator and the presenter to help examine the presenter's focusing question. During my training, I learned the importance of preparing for a meeting by using a pre-conference between the facilitator and the presenter. This meeting allows the two individuals to be on the same page about what the presenter wants to accomplish during the meeting, and the discussion between the two helps to determine the protocol that best fits the situation. The protocol is then used as a guideline for the facilitator as he guides the discussion through a variety of stages, often including rounds of clarifying questions, probing questions to help the presenter think more deeply about the question, feedback, and reflection.

One of the things I valued most about being in KSTF was the quality of thinking and reflecting I had when talking with Fellows.

At the end of my training, I had this grand vision, thinking, "wouldn't it be so cool if we had CFGs in place throughout our entire school, a place to meet once a month and have these sorts of positive, constructive conversations we had been having throughout this week of training?" As I was getting excited to bring my newfound knowledge back to my school, I came to one big realization: there was only one trained CFG coach (me), 45 teachers in my building, and no possible way I could facilitate the whole building in a group. I would need some help. Additionally, there were the tasks of getting teachers to buy in to the CFG model, setting up meetings to be as successful as possible, and hoping that these efforts would somehow be more sustainable than the typical fads in education that last only one or two years.

There was certainly a lot of work to be done.

At the start of the new year, I spent a full day training a group of new facilitators, utilizing a structure

similar to the one used in the NSRF training. This day was designed to allow my group to develop trust with one another, set up norms for how our group could work the best, and gain confidence in how to participate in low-risk protocols. Doing this not only helped us get our feet wet in working with protocols, but also in becoming more comfortable with one another before we started talking about deeper issues.

Another takeaway for our group on this day was understanding the importance of listening and of silent reflection. Since my trainees were all leaders in their own departments, they were very used to being the ones doing the talking in their meetings. Hence, when a protocol required that they be silent for a period of time, I could feel the anxiety level rise in some people. I remember hearing one teacher say that it was extremely difficult for him to sit and be quiet, and to not fill up "dead air" when someone else was allowing time to reflect.

> **Teachers have told me that they now feel a greater sense of community within their CFG that they did not have before.**

We continued training once a month after school, where we would work on tuning lessons and assessing student work collaboratively. By the end of the school year, word was spreading about how positive our CFG experience was becoming, and people were wondering how they could become a part of their own CFG. Similarly, many people were also wondering what went on during a CFG; as a result, we decided to run a tuning protocol for the staff for anyone who wanted to observe. The response was overwhelmingly positive, and nearly three-fourths of the staff voluntarily signed up for a CFG the following year.

At the start of the new school year, we had placed everyone who expressed interest in joining into a

CFG, setting up the groups to diversify subject matter as best as possible. With CFGs now in place, the last piece of the puzzle involved how we were going to incorporate the non-CFG members into the existing groups by the end of the year.

Prior to starting CFGs, it was everyone's understanding that all teachers would eventually be put into a CFG; it was up to the participants whether they wanted to start in right away or delay entering. While placing these individuals into a group might seem trivial, the issue of building up that trust among members loomed over my head since we had already spent so much time doing this earlier in the year. In talking with other teachers about how they felt joining the CFGs, I could tell that there was some anxiety about participating in discussions about our own teaching practices.

Overcoming such anxieties is not easy, and while spending hours together working on listening and communication skills with one another helps to gain some of that trust, we will have to continue being proactive about building trust and professional relationship with each other, especially those teaching different subject matters. Even in the short time that CFGs have been a part of my school, there have been some positive noticeable changes. Teachers have told me that they now feel a greater sense of community within their CFG that they did not have before. I know I personally felt this after I had my knee surgery, and from the moment I returned to school, saw that so many people (especially in my CFG) would go out of their way to bring me ice, make my copies, and do anything else that would be difficult for me to do on crutches.

Others who were very skeptical of the whole thing have said that they really appreciate getting together and having these professional discussions. For instance, a foods teacher at my school didn't think anyone would want to hear about the issues she had with the reflective portion of a cooking assignment. However, after presenting the lesson and doing a tuning protocol on it, she gained enough feedback from her group to adjust a future lesson.

On a personal note, I learned a great deal about teacher leadership outside of my classroom throughout this entire process. One thing I found particularly challenging was feeling a constant pressure to make sure things went smoothly so

Photo by Dwight Cendrowski

course, there are going to be frustrations among group members, and it is impossible to make everybody happy. But if you have the perseverance to work through these obstacles, and have enough people around you who believe in what you are doing, the right attitude can go a long way.

While I cannot predict what will become of our CFGs in the years down the road, I am excited about the possibilities. For instance, we have started using peer observation and video protocols this year, and some teachers even hope to use simple protocols in their classrooms to teach students about listening to and discussing with each other.

Sure, critical friends groups are not going to bring the KSTF culture into my school on their own; it's going to take a lot of time and conscious effort by me and others to change how we talk about teaching and learning with one another. But now that we have a place for these types of professional discussions, I can hopefully bring my school a little bit of the KSTF culture for years to come.

REFERENCES
Bambino, D. (2002). Critical friends. *Educational Leadership*, *59*(6), 25–27.

National School Reform Faculty (NSRF): http://ow.ly/KyEQA

NSRF Critical Friends Resources: http://ow.ly/KyriR

CITATION
Chen, V. (2015). Bringing a slice of KSTF to my school: How starting critical friends groups has helped create a space for professional reflection and discussion. *Kaleidoscope: Educator Voices and Perspectives*, *1*(2), pages 15-18.

that people bought in to what we were doing. Thus, I made sure to pay close attention to the details of whatever we were doing for each meeting. In addition, I learned how important it is to trust other people. Since we had seven other facilitators working with various groups in the school, I had to trust that people were going to do their best to ensure as much success as possible, and that I could offer my assistance if extra support was needed. I learned the importance of listening, even during the times I felt like saying something. And I learned that a project of this magnitude takes a lot of time and patience to do well. In an era where everyone wants immediate results and feedback, I am thankful that we did not rush through the details to get CFGs into our school.

Finally, I learned that even the best-laid plans don't always work out the way you want them to. Of

I learned that a project of this magnitude takes a lot of time and patience to do well. In an era where everyone wants immediate results and feedback, I am thankful that we did not rush through the details to get CFGs into our school.

FOUR PHASES OF THE ENGINEERING DESIGN PROCESS IN MATH AND SCIENCE CLASSROOMS

BY KELSEY JOHNSON, SCOTT MURPHY, CASEY O'HARA, AND KATHERINE SHIREY

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INTRODUCTION

The KSTF Engineering Task Force (ETF) has been examining how to integrate engineering projects and processes into math and science classrooms. It draws on Teaching and Senior Fellows' classroom experience. The Senior Fellows that make up the ETF are life science teachers, physical science teachers, math teachers, and even engineering teachers. Some of us are novices whose boundless enthusiasm makes up for our lack of engineering experience; others bring expertise based upon engineering degrees and years of experience in the field.

At the initial meeting of the ETF in summer 2013, we considered the initial question: "What is important in engineering design?" Through a rich and often boisterous discussion, we collectively broke down the engineering design process into four main phases: problem definition, design exploration, design optimization, and design communication.

The ETF's first three phases align well with the three-phase process outlined in the Next Generation Science Standards (NGSS), with an additional phase to emphasize design communication. We have chosen to represent each phase with a circle instead of an arrow because the engineering process is iterative, not linear. Imagine that each circle is a gear that helps turn all of the others in an effort to complete the whole process. In the first two phases, the engineering process is divergent, where the engineer/student is expanding the design space through brainstorming and creativity. The latter two phases focus on narrowing down the choices, converging to a single, optimized solution.

Engineering Design Process Developed by KSTF Engineering Task Force

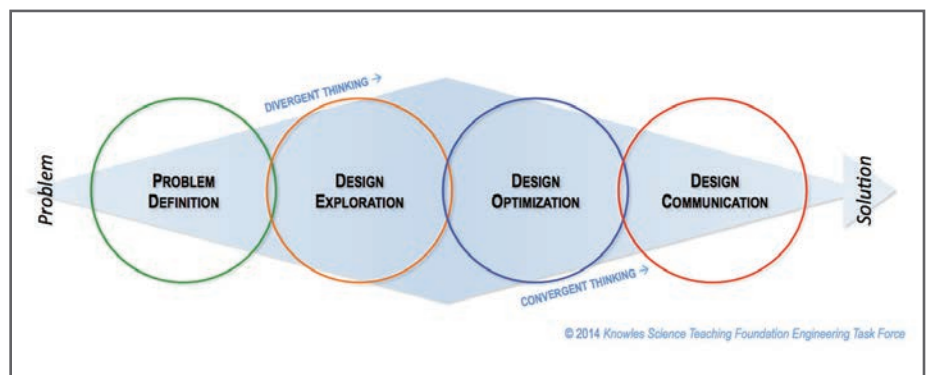© 2014 Knowles Science Teaching Foundation Engineering Task Force

Photo by Katey Shirey

Students work on a newspaper support structure challenge to learn about the four phases of engineering

Each phase offers different rewards and challenges for students, teachers, and engineers, and each phase is critical within the larger process of moving from problem to solution. In the article below, four members of the ETF have each selected one phase, crafting an argument for why we feel that phase is so critical to the engineering design process. We hope that this article will help you understand the engineering design process, provide an impetus for you to incorporate engineering into your classroom, and consider which phase you think is most crucial to the process.

PHASE 1:
PROBLEM DEFINITION BY CASEY O'HARA

It is often said that a scientist is not one who gives the right answers, but instead asks the right questions. It might as easily be said that an engineer is one who identifies the right problems. A vague notion of a problem, expertly framed, becomes a worthwhile engineering task. Clever framing can focus attention on one aspect of a grand issue, or can "embiggen" an otherwise trivial problem. In establishing the scope, constraints, and criteria of an engineering problem, problem definition becomes the single most influential phase in the design process.

Let's examine a broad, challenging problem: cooking practices in rural communities in developing countries are often terribly inefficient in fuel use, create dangerous indoor air pollution, and contribute to carbon emissions. For this example, I will put myself into the shoes of a student, given only the

broad problem statement above as my guidance. First, let's narrow the scope to focus only on cooking practices in rural Kenya. I could have selected a different country, with different practices and needs, or defined an inclusive scope that addresses concerns across many contexts; different choices in scope would likely result in different products at the end of the process.

Let's establish some constraints, consistent with the chosen scope. With a little research I found that rural Kenyans rely almost exclusively on wood as cooking fuel; I will constrain my design to use wood as fuel, to accommodate existing cultural norms. I might set constraints in price and materials, ensuring that my design is affordable for the average Kenyan family. Again, I could choose different constraints, understanding that this would certainly impact the final design.

It is often said that a scientist is not one who gives the right answers, but instead asks the right questions. It might as easily be said that an engineer is one who identifies the right problems.

Finally, I must determine criteria by which I would evaluate my design. I would like to increase fuel efficiency, reducing both fuel costs and carbon emissions. I would also like to improve indoor air quality and minimize cost. How I choose to prioritize these criteria drives choices involving tradeoffs. For example, adding a chimney to vent exhaust gases might greatly improve indoor air quality, with less improvement to the stove's cooking efficiency, and likely at a higher price. Which design is preferable? It depends entirely on my priorities established in this phase.

The final outcome of any engineering design project depends on choices made in each phase of the

Students gather data using an optics bench to optimize their lens placement while designing a telescope

Scott Murphy

is a KSTF Senior Fellow who teaches physics at St. Joseph's Preparatory School, which is located in Philadelphia, Penn. After starting to use engineering design in his classroom, he proposed that his school have a special engineering class that he will design and teach during the 2015–2016 school year. He is a member of the KSTF Engineering Task Force.

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Casey O'Hara

is a KSTF Senior Fellow. For eight years, he taught physics, integrated science, and engineering & green technology at Carlmont High School in Belmont, Calif. In 2014, he completed a Master of Environmental Science and Management at University of California, Santa Barbara's Bren School and an American Association for the Advancement of Science (AAAS) Mass Media Science & Engineering Fellowship at *The Oregonian*, in Portland, Ore. Currently, he is conducting research on marine energy resources and ocean conservation. Casey is a member of the KSTF Engineering Task Force and the KSTF Journal Editorial Board.

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process. But this initial phase—problem definition—establishes the framework within which all other engineering decisions must be made and evaluated. And this extends far beyond engineering—as students develop skills in critically examining problems and defending rational decisions about priorities, they develop a conceptual toolbox to approach problems in any science or math class, as in life.

As teachers, it can be a little daunting to relax our grip on our curriculum, to give our students the freedom to push the bounds of an in-class project perhaps beyond our own comfort levels. But the student engagement and empowerment that results is certainly worth the effort. We want our students to ask the right questions and to identify the right problems—that's where the engineering starts.

PHASE 2:
DESIGN EXPLORATION BY KATHERINE SHIREY

The second phase of the engineering design cycle is the most important in high school engineering: design exploration. It is here that the student-engineer develops a potential solution and where the direction of the classroom is steered away from the teacher and towards the student. In phase two a student-engineer takes a problem statement with constraints and begins to make her investigation into what would best solve the problem. She generates and compares design alternatives through systematic modeling, testing and comparison. At the end of phase two she has a preliminary design that approaches or meets the list of required functions, criteria and constraints from phase one.

Significantly, phase two allows solutions to diverge widely and encompass student interests and curiosities without restriction. It reorients the classroom away from teacher-directed instruction and sends students into a hunt for the best solution. In this way the design exploration phase is the most open-ended and student-centered portion of the engineering design process. Phase two represents a significant divergence from typical models of science instruction where instruction starts with a teacher sharing information with students through lecture, and then students familiarizing themselves with the information by conducting a lab or solving sample problems before being graded on their retention.

In design exploration, however, a student-engineer is encouraged to brainstorm a flurry of design ideas, gather data multiple times on any number of questions that will help to evaluate the ideas, and use other tools, such as a Pugh Chart or decision matrix, to evaluate the designs. There is no predetermined answer to be verified, only limitless imagination to be explored and compared. As they test ideas, students will investigate physical and mathematical constraints—the subject content that a teacher may wish them to "cover" in a more traditional lab.

Last summer I asked 26 high school students at a science and math enrichment summer camp to design a doghouse that would stay warm in the winter and cool in the summer. Students brainstormed, debated, and defended their ideas for the best materials: shingles, wood, foam, aluminum foil, carpet, plastic sheeting, mirrors, tubes, vent panels, solar panels, fans, ice and more. In small groups, students built mock-ups to compare various ideas before deciding on the most important, appealing, and successful designs to carry forward into the next phase. One group decided to pursue a balloon cooling mechanism to blow air into the house; another group proposed a vaulted, open-air second story for the dog to retreat to on hot days.

Without limits or bounds for design, the students worked with deep complexity and interest, all the while developing a better understanding of science content. For instance, they learned how a "biology word" like homeostasis relates to insulation, heat transfer, homes, and energy.

In summary, the design exploration phase of engineering design shifts the purpose of classroom activities away from that of teacher demand and approval, and toward student interest and student evaluation, increasing the intrinsic motivation that students have towards their work.

PHASE 3:
DESIGN OPTIMIZATION BY SCOTT MURPHY

Humans have been trying to solve problems since the inception of human existence. Common sentence starters include, "I wish that …" or "Hey, I've got a great idea…" The first allows people to identify a problem or a need; the second allows people to explore a design. However, the science of engineering reaches a crucial maximum when we start optimizing our design.

For instance, travel across a long distance has improved tremendously, allowing people to meet, share ideas, and explore new terrain. Think about the automobile; the structure of the car remains largely the same as Henry Ford's Model T. However, that has not stopped car manufacturers from employing legions of engineers. The problem remains defined (how do we get from Point A to Point B?) and the essential design is very similar. That leaves the process of optimizing the design, given changing priorities.

As teachers, it can be a little daunting to relax our grip on our curriculum, to give our students the freedom to push the bounds of an in-class project perhaps beyond our own comfort levels. But the student engagement and empowerment that results is certainly worth the effort. We want our students to ask the right questions and to identify the right problems—that's where the engineering starts.

Companies establish their criteria and priorities in the first phase of the process. They want cars to be affordable, meet certain mileage standards, and be fun to drive. The car must be comfortable; the car must be safe; the list continues. However, until a prototype is actually built, this wish list is simply that—a wish! Engineers are continually collecting data and using that data to make informed decisions about what solutions will yield the best end product. In the classroom, this might look like students building a gravity car based on a set of constraints (e.g., needs to travel a certain distance, stop, complete the trip intact), making a high level engineering project accessible for all students.

After the criteria and constraints are established, the metaphorical rubber of engineering practices

meets the road of reality. Everyone would love to build a cheap car that is safe, fuel efficient, and fun to drive. When others would use their gut instinct and hope for the best, the engineer uses data to make decisions. Each time new data becomes available, the engineer returns to the design to improve it. As science continues to discover new ideas and possibilities, the engineers continue to reevaluate their decisions to create the best possible solution. This iterative process separates engineering from other approaches, allowing for the best possible outcome given a set of circumstances. This is an opportunity for students to engage in authentic science dialogue in the classroom. As students collect data on individual variables, they will need to share their information with their classmates in order to determine the most effective design.

Once a decision has been made, it is time to build and test the concept. Without an actual prototype to test, all of the work is theoretical. This stage is where the engineer confirms the viability of the solution. Often there is a good deal of fine tuning that needs to take place after the construction of the prototype that was not anticipated in the earlier stages. For example, musical instruments are constructed with tuning capabilities to account for small deviations that occur in the physical reality, but not in the abstract theory.

I use this process in my classroom when I give my students the task of constructing their own musical instruments. As students learn about sound and waves, these physical concepts are quite abstract and difficult for them to internalize. By affording students the opportunity to hear the different notes based on changing the design characteristics, constructing a prototype allows students to see how engineering is a relevant skill that they can apply outside the classroom.

This kinesthetic learning helps make science, math, and engineering accessible to students with many different learning styles as they get to actually see their ideas come to fruition. Without the third phase in the engineering cycle, engineers would simply be the philosophers of the science world.

PHASE 4:
DESIGN COMMUNICATION BY KELSEY JOHNSON
The fourth phase of the engineering design process provides the most leverage for engineering's power and utility. Communication is the alpha and omega of engineering; it provides both the invitation and the legacy. Rather than terminating a linear process, communication acts as a revolving door from one design cycle to the next. Our collective body of knowledge, our human inheritance, has grown since people first identified problems or designed and optimized solutions.

The design exploration phase of engineering design shifts the purpose of classroom activities away from that of teacher demand and approval, and toward student interest and student evaluation, increasing the intrinsic motivation that students have towards their work.

Poet Charles Bukowski writes, "genius might be the ability to say a profound thing in a simple way." Similarly, communication in engineering is not about rhetoric, popular oratory, or winning more followers. Instead, it's about sharing information so that people, possibly distant in space and time, can use that information to advance the wheel rather than reinvent it. Effective technical communication requires concise, compelling argumentation. Digital media now enable students to engage in this human conversation with unprecedented access and voice. Students showcase their achievements and learn from one another when schools prioritize design communication. For example, schools like the New Tech Network and High Tech High integrate design communication into their academic calendar by utilizing student exhibitions as both a deadline for student accountability and airtime for student voice and growth. A light of motivation ignites in students

when they hear calls to solve real engineering problems and have enough scaffolding to engage in all four phases of the engineering design process. Similarly, national calls by organizations like the BentProp Project, First Robotics, and Progressive Automotive X Prize invite high school students to participate in solving real-world problems and to communicate their designs in authentic, inspiring competitions.

Access to information and physical resources are arguably the rate-limiting steps in solving technological problems. As technology enhances the speed that resources can travel over great distances, it also improves the speed with which information can be shared. Communicating evidence-based, logical arguments about what makes a design optimum, what's been tested and rejected and why, students, scientists and engineers add to our legacy of knowledge at a groundbreaking rate. As our world gets flatter, the fourth stage of the engineering design process provides the guiding light to a better future.

CONCLUSION
Members of the KSTF ETF consider engineering a vehicle to engage students through creative, authentic problem solving. In presenting each phase of the design process separately, our aim was to create an evidence-based argument for the value of the engineering design process as a whole. We hope that this article has helped clarify the different phases of the engineering design cycle and why each is important for our students.

The ETF's vision is that all students will get to experience a comprehensive engineering design project in their science or math class, from problem definition through design communication, and that every teacher will have the confidence and resources to provide this opportunity for their students. But we recognize that it might be overwhelming to involve all four cycles of the design process during your first attempt at employing an engineering project in your classroom. It is often easier, for both teachers and students, to start with a lesson that teaches one or two design phases before working up to a full-blown engineering project. We encourage you to start small and modify a pre-existing lesson and experiment to see what happens.

FOR MORE INFORMATION
If you are interested in more information please reach out to any of the authors or Dina Portnoy, KSTF's Director, Senior Fellows Program (dina.portnoy@kstf.org). Additionally, more information on how to incorporate engineering in the classroom can be found at the KSTF ETF Resource Center: http://ow.ly/KysPJ. We are very interested in supporting and/or collaborating with other teachers who would like to incorporate engineering into their classrooms. Happy building, happy designing, happy learning!

REFERENCES
High Tech High: http://ow.ly/KyFMW

New Tech Network: http://ow.ly/KyFOI

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Johnson, K., Murphy, S., O'Hara, C., & Shirey, K. (2015). Four phases of the engineering design process in math and science classrooms. *Kaleidoscope: Educator Voices and Perspectives*, *1*(2), pages 19-24.