Lessons in life sciences

College-bound students enroll in new courses as agriculture joins Indiana's science curriculum

By Jennifer Cummins

Seth Edwards concocted a recipe for spicy miniature turkey franks from scratch, while his classmate Josh Twitty perfected his Thanksgiving dinner-inspired turkey smoothie.

Edwards and Twitty, both 2008 graduates of Lebanon High School, in Lebanon, Ind., participated in a program that combines agriculture with the practical application of advanced life science concepts. Students have challenging, college-level coursework and hands-on lab experiences—like processing an entire turkey into new products.

The Advanced Life Science (ALS) program, a joint effort between the Purdue University College of Agriculture, the Indiana Department of Education (IDOE) and the state's science community, was designed to help combat a projected shortage of qualified life-science workers in the state.

The program, one of the first of its kind in the nation, puts three agriculture courses on equal academic footing with traditional college-prep science classes. The three courses, "Advanced Life Science: Animals," "Advanced Life Science: Plants and Soil" and "Advanced Life Science: Foods," satisfy science requirements for both the Indiana academic honors diploma and the Core 40 diploma—recommended curricula for students who plan to continue their education. Three Purdue credit hours are awarded for animal and foods courses, and four credit hours are awarded for the plant and soil course.

In the beginning

The ALS program is the brainchild of a life sciences task force charged to create a set of courses that would prepare students to function in a scientifically complex world. "Indiana was breaking new ground—academic science and agricultural science teachers are learning and working together to build stronger junior- and senior-level science programs for our students," says Dorothy Winchester, IDOE director of academic programs. "The strength of these courses is that they offer rigorous life science programs in the context of agriculture—an industry that is very important to Indiana's economic well-being.

Each of the courses builds on basic science prerequisites, such as biology and chemistry, to help students better understand how Indiana's agricultural industry is grounded in science application and research."

A domino effect

Beginning with the 2004-05 school year, the courses were unveiled, one each year, in schools throughout Indiana. All three courses are now taught to approximately 1,100 students in more than 100 Indiana high schools.

"Students around the state are engaged in high-end research and laboratory work that, in the past, would only have been available to graduate students," says Roger Tormoehlen, head of Youth Development and Agricultural Education. At Owen Valley High School, in Spencer, that research includes experimenting with DNA extraction, while at North Montgomery High School in Crawfordsville, students are testing lipids and fats. Other schools performing high-tech experiments are Eastbrook High School, in Marion, where students are researching the process of osmosis, and Maconaquah High School, in Bunker Hill, where students are studying genetics and genetic mutations.

"Not only does the ALS program positively impact students' lives, but the demand for the courses has opened up new and exciting opportunities for agricultural education graduates," Tormoehlen says. Many schools either added or expanded agriculture programs just to accommodate the courses. "The schools near Indianapolis were some of the first, and it has really been a domino effect from there."

One of the first schools to offer the courses was Lebanon, which previously didn't have an agriculture program. The school committed space to agriculture classes, acquired an agronomy farm and hired Purdue animal science

Madeline Wilhoite (left) and Ellen Carrell were among the more than 1,000 Indiana high school students who enroll in Purdue-developed advanced life sciences courses each year. The students' ALS Plants and Soils class at Lebanon High School attended Purdue botanist Michael Zanis' (pictured here) Introduction to Plant Science course.

and agricultural education graduate Byron Ernest to bring it all together. "We started our agriculture program four years ago and built the curriculum around the advanced life science courses," Ernest says. "Once we started offering the courses, they soon became very popular with our college-bound students."

As the recipient of a Distinguished Fellow Lilly Teacher Creativity Grant last year, Ernest was able to bring his "ALS Plants" students to Purdue for Michael Zanis' Botany 210 lectures and labs. "I try to make sure that the courses are a mirror image of the equivalent concurrent credit courses at Purdue," Ernest says.

Kick start to college

Beyond working in laboratories in their own schools and at Purdue, ALS students have the opportunity to visit agri-science companies to get a first-hand look at the agriculture industry outside of farming. That way, whether or not students have a farm background, they can find interest in other areas of the industry.

"I didn't grow up on a farm and don't really have any farming experience, but through the Lebanon agriculture program I learned that agriculture is so much more than farming," says Cayla Mustin, a 2008 graduate of Lebanon High School. "I started to develop an interest in horticulture, so when the ALS classes came to Lebanon, I signed up. I'm in awe of the program, and, when we visited Purdue, I got a real feel for what I want to study in college."

Mustin's former classmate Madeline Wilhoite was raised on a hog and grain farm, but found that farming wasn't the only aspect of agriculture that interested her. "My family farms, and I show cattle, hogs and sheep, so I grew up knowing I was interested in agriculture," says Wilhoite, also a 2008 Lebanon graduate. "But, even so, the plant and soils class and the hands-on science field trips helped me to know that I want to study horticulture at Purdue."

Wilhoite and Mustin, also a horticulture major, entered Purdue already having science credits and experience in college-level labs and coursework. Edwards, who is studying agronomic business and marketing at Purdue, and Twitty, a livestock production major at Ivy Tech, have hands-on research—and inventive food processing experience—to go along with college credit earned. "Showing relevant and practical science applications early on helps students to see that there is a purpose to what they are learning," Tormoehlen says. "Plus, when they graduate high school, they already have college credits and are well on their way to exciting careers."

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URBAN AGRICULTURE PROGRAMS ON THE RISE:

Agriculture Education Model Can Reach Students Other Classes Leave Behind

By Julie M. Fritsch

Agricultural education, a long-time mainstay in rural schools, is finding a new foothold in cities where teachers and administrators are discovering that its unique educational model, which combines hands-on classroom activities, integrated leadership education and carefully selected real-world experiences, provides the relevancy and concept reinforcement that can help all students achieve, even those who may be below grade level or at risk of failing.

Agricultural education is more than just a way to describe classes about food and farming-related topics; it is an educational model comprised of three integrated components—classroom instruction, leadership education, hands-on experience—referred to by agricultural educators as the Three-circle Model. Each of the three circles overlaps with and reinforces the other (Figure 1).

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The Real-world Application of Science and Math Concepts

Agricultural education begins with hands-on classroom and laboratory instruction. Because agriculture is such a broad topic, schools typically tailor agriculture class offerings to match the interests of the student population, needs of nearby businesses and industry, or topics relevant to their state's standard assessments.

Within most agriculture programs, concepts in individual classes build on concepts found in other agriculture, science and math classes, so as students progress through school, they see how what they are learning is interconnected, as well as connected to their everyday lives. Because students in urban agriculture programs usually do not have any background in or interest in production agriculture, classes often focus on topics like biotechnology, food science, agricultural engineering, veterinary science or horticulture.

"It comes down to the philosophy of students learning in areas where they are interested, in a context that's relevant to them," said Byron Ernest, principal at Emmerich Manual High School in Indianapolis, Indiana. "We know that when you have students who are not at grade level, relevance becomes very important to them. If they don't understand how something relates to them, they aren't going to do very well. Agriculture is something everybody can relate to."

Emmerich Manual High School, Emma Donnan Middle School, and Thomas Carr Howe Community High School were the lowest-performing schools in the Indianapolis Public School system for several years in a row, prompting the Indiana Department of Education to take control in 2011 and turn over their management to Charter Schools U.S.A., an education management company. Among the changes made by Charter Schools U.S.A. was the implementation of an agricultural education program at each of the three schools.

Ernest feels confident that the agricultural education model will help the schools get back on track. Prior to taking the job as principal at Emmerich Manual, Ernest started an agriculture program at Lebanon High School, another urban school near the outskirts of Indianapolis. "The program now has four teachers and over 600 students. The students get it, the community gets it. It's a really, really good way for students to learn."

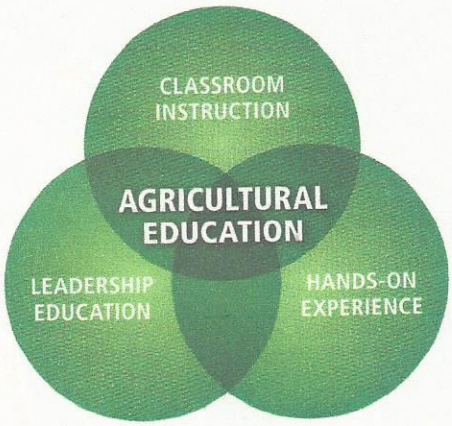
Currently, students at the three Indianapolis schools can take a Fundamentals of Agriculture class, which counts as a high school credit, even for the middle schoolers. The eventual goal is for students at the three schools to begin their agricultural education experience in middle school with the Fundamentals class, then progress through high school on one of three agriculture tracks —one that is life-science based, one that is business-oriented or one that is more focused on graduating with the skills to go into a trade or technical school after graduation.

"We understand that every student may not eventually continue on to college, but we want them to leave here college ready, and if we've done our jobs, they will also be career ready," said Ernest.

"This group of kids needed a hands-on, technical approach to learning," said Dave Davies, the agriculture teacher at Emma Donnan Middle School. Davies, previously an agriculture teacher at a rural high school in Indiana, was recruited to Emma Donnan by Charter Schools U.S.A. to help start the agriculture program. "By using a different form of education than they're used to, we hope to get them interested and keep them in school."

Davies describes his Fundamentals of Agriculture class as heavy on science and common sense agriculture. Students in his class recently completed a unit on corn and oil crops, where they burned corn and nuts and did taste tests on different types of cooking oils. Currently, they are learning about eggs, including their structure and how to tell if they are fertilized. These lessons tie directly into science concepts students are learning in their other classes.

Figure 1: Ag Ed Three-circle Model



Teachers at the schools are coordinating their curriculums so that they cover concepts in science and math classes at the same time as the agriculture classes. In a recent discussion with his agriculture teacher at Emmerich Manual, Ernest discovered that some students were enrolled in both agriculture and biology, and both classes were studying genetics. The agriculture teacher said that learning the concept of genetics in biology class, then discussing the practical application of that in agriculture class through a lesson about the interbreeding of horses and zebras, got the students excited about the concept and encouraged them to explore the concept further.

"It challenged the students and extended the learning, and that's the goal," said Ernest. "After those discussions, the students understand why they are learning genetics." Without the "why," said Ernest, students like those at the three turnaround schools are less likely to learn the lesson.

Integrated Leadership Education

At Emma Donnan, Davies integrates presentations, debates and group work into his lessons as often as he can, which tie into the second circle of the agricultural education model—leadership education. "Any time I can get the students up speak-

PHOTO COURTESY OF JESSICA MCATAMNEY

▲ Students at W.B. Saul High School in Philadelphia preparing to install irrigation lines to the school's orchard.

ing, researching and taking the lead in their education, I feel like we're successfully educating these young adults," he said.

Besides in-class leadership activities, the leadership education circle of the agricultural education model is often delivered as FFA (Future Farmers of America)—a student organization that focuses on activities like committee and board leadership, public speaking, civic service experiences, and team and individual contests based on subjects learned in the agriculture classroom. Unlike other student organizations, FFA is considered intracurricular, not extracurricular. This means that events, especially contests, are often based directly on concepts students learn in class, and FFA activities can sometimes count for class credit.

Davies also uses FFA to give his students opportunities they would never otherwise have. Just a few months into the school year, he has already taken them to a working farm, the National FFA Convention, and has plans in the works for a community service project.

"We have to show them there's something outside of what they know right now," he said. "So many of my students have never been outside of the I-465 area."

A moment Davies is especially proud of is when he allowed his ag students to write their own bylaws for their FFA chapter. "Typically, there's a first vice-president and a second vice-president," he said. "The students wanted everyone to be equal, so they came up with the titles of 'vice-president of academics' and 'vice-president of community outreach.' It was great to see them take ownership and figure it out like that."

Outside of Classroom Projects

The final component of agricultural education, experiential learning, requires that each student has a long-term, out-of-class project that relates to agriculture. Projects might take the form of a lawn-mowing business, growing vegetables or producing eggs and selling them, or working for a community agriculture-based business or organization.

Experiential learning can be challenging for urban students because they don't usually have land they can keep animals or grow plants on. Additionally, students with backgrounds like those at the three Indianapolis schools also often lack the adult support outside of school to carry out extensive projects like starting a business.

"We are 100 percent free lunch," said Davies. "Many of my students have only one pair of clothes, come from a broken family or have a family member in jail or prison. I have so many students who want to succeed and be successful, but they don't know how or have never been told that they can."

"Our vision for that is more of an internship-type approach," said Ernest about the experiential learning portion of agricultural education at Emmerich Manual. None of the three schools has put the final circle of the model in place yet. "Eventually we would like to start a relationship with agriculture-based businesses in the area and place students there."

Long-term Results

The long-term goals for the three Indianapolis schools aren't just wishful thinking. Although urban programs are rising in popularity, some large urban school districts have had agriculture programs for many years. For instance, W.B. Saul High School in Philadelphia, Pennsylvania, has been an agriculture high school since it opened in 1943. The face of the school has changed over time to keep pace with preparing students for what the state mandates as high-priority careers, but the focus has always remained on agricultural education.

Seventy-nine percent of W.B. Saul's students are minorities, and more than 73 percent are classified as economically disadvantaged. Yet students at W.B. Saul are above average compared to other Philadelphia public schools in every measured category of student achievement, including performance on the Pennsylvania System of School Assessment. Just as importantly, they rank in the top 25 percent of all Philadelphia public schools in three of the

four indicators of college and career readiness—PSAT/SAT/ACT participation, being on-track to graduation and having a low drop-out rate.

Students from across Philadelphia undergo a competitive application process to attend W.B. Saul, agree to attend a challenging summer orientation program as freshmen and make their way across town in school-subsidized public transportation to attend classes.

"We have a magnetism here," said Jessica McAtamney, a teacher at W.B. Saul. "It's a safe place, the teachers are passionate, it's hands-on learning; there are high expectations for the students. It's a different model of education than students could get at a regular high school. It's challenging."

Currently W.B. Saul, which has 15 agriculture teachers, has four educational tracks students can choose to pursue—food science, small animal science, large animal science and natural resource management. Students spend their freshman year exploring each of the four tracks, then choose one to follow through the rest of their high school career.

No matter which track students choose to pursue, the hands-on component of agricultural education adds a new dimension to their educational experience.

"Often our students have never been asked to physically perform before," said McAtamney. "They've never mucked a stall or pulled an acre of weeds."

And then there's the science. "It's a real turning point for a lot of students when they understand just how much science is involved in these classes," she said. "It's experiential education at its finest," notes McAtamney. "We learn about it, and then we do it. We're going out on Monday to plant the strawberries. You couldn't do that at just any school."

For McAtamney, Ernest and Davies, and agriculture teachers like them, urban agriculture programs aren't just one way to reach students who may be disadvantaged or struggling. It's the best way.

"My ag students are better behaved, are achieving more academically, are more outgoing, and have been able to problem-solve better than the rest of my students," said Davies. "In addition, students who had problems speaking out in front of their peers are now speaking in front of each other and are able to present to the class when at first they could not." T

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The Flight of the Space Shuttle *Discovery* (STS 119)

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This article is intended to model the ascent of the space shuttle for high school teachers and students. It provides a background for a sufficiently comprehensive description of the physics (kinematics and dynamics) of the March 16, 2009, *Discovery* launch. Our data are based on a comprehensive spreadsheet kindly sent to us by Bill Harwood, the "CBS News" space consultant. The spreadsheet provides detailed and authentic information about the prediction of the ascent of flight STS 119, the 36th flight of *Discovery* and the 125th shuttle flight to date. We have used the data for our calculations and the production of the graphs. A limited version of the ascent data is available on the "CBS News" STS-119 trajectory timeline.[1]

Using the NASA data

The complete description of the ascent of the space shuttle, placing the orbiter into a preliminary orbit, is a formidable engineering task, but it is clearly also a computational challenge. First, we had to decide what data were useful and relevant; second, we went through the task of converting the units into the SI system; and third, we looked for key positions of the shuttle's trajectory to illustrate the physics (kinematics and dynamics) of the ascent.

The immediate task of finding the important columns of the spreadsheet was difficult, mainly because the vast majority of the entries turned out to be irrelevant for our purpose. The columns we finally decided on can be seen in Tables I and II.

The second task, that of converting the units to the SI system, was straightforward. However, we are tempted to ask the following question: Why is NASA still using the British system of units?

For the third task, that of choosing representative points in the trajectory, we analyzed three key times, the first at the very beginning of the takeoff, the second when $t = 60$ s, and the third when $t = 480$ s. The first one is important because it discusses the near-static condition when forces are applied that allows the shuttle to rise in the gravitational field of the Earth. The second position is instructive because the shuttle is entering a curved motion, significantly departing from the near-vertical ascent during the first 30 seconds. This allows the analysis of the forces acting on the shuttle as well as on the astronauts, including the force of the air drag, which at this time is a maximum.

The third and last position chosen is the time just before main engines cut off (MECO). Here the horizontal acceleration is a maximum (almost $3g$), the drag is zero, and the orbiter (plus external tank) is moving in a near-horizontal direction. In addition, the centripetal acceleration is 8.1 m/s^2 and the astronauts are beginning to feel being "weightless"; that is, they are in what NASA designates as *microgravity*. We will conclude with some suggestions for a number of additional problems.

The launching of the space shuttle

The following description of the flight of the space shuttle is partly based on the *News Reference Manual*[2] originally distributed to the press in 1988 and the shuttle reference data located on NASA's website.[3] However, the data we use are from a recent flight of the shuttle (Flight STS 119). It should be explicitly stated that data given to us, about six weeks before the launching, were a *prediction* and not the data of the actual flight. Please consult the tables when reading the description of the flight.

Initially, the space shuttle, consisting of three major components [the orbiter, the solid rocket boosters (SRB), and the external fuel tank], is launched vertically with all main engines firing. About 10 s into the flight, the shuttle turns so that the orbiter lies under the external fuel tank and the solid rocket boosters. This familiar roll is important for a number of reasons. First, it reduces the stress on the orbiter's delicate wings and the tail of the shuttle. Second, it makes it easier for the computer to control the shuttle during the remainder of the ascent. Third, it enables the astronauts to see the horizon, giving them a reference point, should the mission have to be aborted and the orbiter forced to land. The roll ends at about 18 s, when the shuttle is at an altitude of 976 m and a range of about 200 m. The velocity of the shuttle now is 120 m/s.

The shuttle then climbs along an arc, accelerating while its total mass decreases. As the shuttle continues to flatten in its trajectory, powering back the main engines to about 70% relieves stress. By about 40 s into the flight, the shuttle breaks the sound barrier with a speed of about 320 m/s. About 60 s into the flight, the shuttle encounters the highest air resistance (drag). At this time the phenomenon known as the Prandtl-Glauert singularity occurs, when condensation clouds form during the transition to supersonic speeds. Shortly after that, however, the pressure on the orbiter decreases and the shuttle engines are returned to full power. At this point, the shuttle is traveling at 454 m/s.

Two minutes (120 s) into the ascent, the Shuttle is about 45 km above the Earth's surface and traveling at Mach 4.1, or 1324 m/s. The SRBs, having used up their fuel, separate from the external fuel tank and fall back to Earth. The descent of the SRBs, some 225 km downrange, is slowed by parachutes that are ejected from the nose cone, marking the end of the

(turn to page 165)

Table I. The Flight of Discovery STS 119: Kinematics

Time (s)	Alt (m)	Range (km)	θ (°)	V (m/s)	Vy (m/s)	Vx (m/s)	Accel. (m/s^2)	NASA Accel "sensed" g	α (°)	28.608N 80.604W
0	-7	0	89.8	0	0	0	4.8	0.3	90	Launch
5	46	0	89.7	24	24	0	6.0	1.6	89	
10	236	0	87.4	55	55	0	7.0	1.7	89	Start roll
15	672	0.18	71.9	97	95	19	8.5	1.8	78	
18	976	0.18	69.2	120	115	34	8.6	1.9	73	End roll
20	1211	0.18	69.5	137	129	46	8.6	1.9	70	
30	2787	0.93	67.8	220	197	97	8.5	1.8	63	
36	4032	2.0	65.9	266	234	126	8.0	1.8	61	Throttle down
40	5214	2.2	63.8	300	257	154	8.1	1.7	58	
50	7890	3.3	61.3	364	300	206	7.1	1.8	55	Throttle up
60	11380	6.5	59.1	454	363	272	10.	2.0	53	Max.AirPressure
90	25496	19.4	38.7	882	576	667	16.	2.5	40	
120	44626	47	26.1	1324	660	1147	8.1	1.0	29	
124	47341	49	25.5	1339	644	1173	8.0	1.0	28	SRB STAGING
125	48162	51	23	1341	643	1176	9.0	1.0	28	
150	63018	84	19.7	1483	545	1379	8.0	1.0	21	
180	77732	129	16.9	1696	437	1638	8.3	1.1	14	
210	89304	181	14.5	1957	334	1928	11	1.2	9	Negative return (218)
240	97930	242	12.5	2258	340	2232	11	1.3	8	
270	104006	315	10	2614	151	2609	13	1.4	3	
300	107416	397	7.8	3007	74	3006	12	1.6	1	
330	108715	491	5.5	3452	10	3451	15	1.7	0	
360	108296	600	9.4	3960	-38	3959	18	1.9	-1	
390	106808	728	25.3	4562	-62	4561	21	2.2	-1	
392	106690	737	25.2	4603	-63	4602	21	2.3	-1	
420	104776	871	22.9	5249	-70	5248	24	2.6	-1	
440	103479	980	21.1	5788	-54	5787	27	3.0	-1	
450	103016	1036	20.3	6062	-40	6061	27	3.0	-1	
480	102661	1225	17.5	6912	26	6911	27	2.9	0	
503	104059	1394	13.6	7571	98	7570	1.4	1.2	0	MECO
510	104718	1444	12.8	7581	98	7580	0	0	0	Zero Thrust
514	105077	1471	12.8	7581		7581	0	0	0	37.356N 68.714W

Table i.

Altitude: The height in m, above the imaginary geodesic point at the launch sight, which is 7 m (-24 ft) above the center of gravity of the shuttle at $t = 0$.

Range: The distance in km at time t, measured along the Earth's curvature to the shuttle.

Pitch Angle (PA): The angle from the horizontal to the shuttle in degrees.

V = Velocity of the shuttle at time t in m/s.

V_y = Vertical component of the velocity of the shuttle at time t.

V_x = Horizontal component of the velocity of the shuttle at time t.

Accel.: Acceleration of the shuttle at time t.

Accel.(NASA): The acceleration reported by NASA, as "sensed" by the astronauts.

α: The angle that the tangent makes with the trajectory (See R-t graph)

Table II. The Flight of Discovery 119: Dynamics

Time	Mass kg	Fuel loss kg/s	Thrust %	Thrust (N)	Drag Pressure (N/m^2)	Vi (Inertial) (m/s)	Accel (m/s^2)	
0	2047249		100	30200000	0	408	4.8	Launch
5	2000356	-11831	104.5	31559000	364	409	6.0	
10	1939932	-12806	104.5	31559000	1833	412	7.0	Start roll
15	1866473	-12274	104.5	31559000	5342	435	8.5	
18	1829536	-12334	104.5	31559000	7948	453	8.6	End roll
20	1804824	-12361	104.5	31559000	10012	465	8.6	
30	1687000	-11182	104.5	31559000	21585	528	8.5	
36	1622233	-10440	90	27180000	27691	566	8.0	Throttle down
40	1572745	-9672	72	21744000	30816	596	8.1	
50	1479240	-9304	104	31408000	33806	656	7.1	Throttle up
60	1385150	-9573	104.5	31559000	35059	736	10.	Max.AirPressure
90	1075485	-8782	104.5	31559000	14270	1163	16.	
120	874387	-2098	104.5	31559000	1737	1617	8.1	
124	866820	-1628	104.5	5486250	1233	1635	8.0	SRB STAGING
125	695925	-1427	104.5	5486250	1230	1637	9.0	
150	657211	-1440	104.5	5486250	614	1792	8.0	
180	612567	-1440	104.5	5486250	216	2014	8.3	
210	567923	-1440	104.5	5486250	33	2278	11	Negative Return (t=218s)
240	523660	-1422	104.5	5486250	4	2580	11	
270	478122	-1424	104.5	5486250	0	2935	13	
300	434007	-1423	104.5	5486250	0	3325	12	
330	389893	-1423	104.5	5486250	0	3767	15	
360	345778	-1423	104.5	5486250	0	4270	18	
390	300240	-1423	104.5	5486250	0	4868	21	
392	297394	-1423	104.5	5486250	0	4909	21	
420	256125	-1423	104.5	5486250	0	5551	24	
440	226241	-1423	104.5	5486250	0	6086	27	
450	212436	-1335	98	5145000	0	6359	27	
480	174764	-1114	80	4200000	0	7204	27	
503	150211	-1292	60	3150000	0	7860	1.4	MECO
510	149690	0	0	0	0	7871	0	Zero Thrust
514	149690	0	0	0	0	7871	0	

Table II.

Time: Time is given in s.

Mass: Mass of the shuttle in kg, at the time indicated.

Fuel Loss Rate: The rate of fuel loss in kg/s at time *t*.

%Thrust: The value of the thrust in N, based on 100% being 30,200,000 N for the total thrust (SRB engines plus the three orbiter engines) up to SRB staging when t = 124 s After that it is based on the orbiter engines output of 5,250,000 N at 100%.

Thrust: The thrust in N at time *t*.

Drag: The effect of the atmosphere on the shuttle, given in N/m^2 at time *t*.

Vi: The inertial velocity of the shuttle, i.e., the velocity relative to the center of the Earth. At the beginning of the launch, the Shuttle is already moving at 408 m/s in an easterly direction because of the rotation effect of the Earth at latitude 28.608 N.

first stage of the ascent. The second stage of the ascent begins at SRB separation, when the main engines have inadequate thrust to exceed the force of gravity since the thrust-to-weight ratio becomes less than one. However, as the engines burn fuel, the mass decreases, the thrust-to-weight ratio increases, and the vehicle starts its acceleration to orbit speed. (Note: at about 228 s the thrust-to-weight ratio is over 1, see Table II on the previous page).

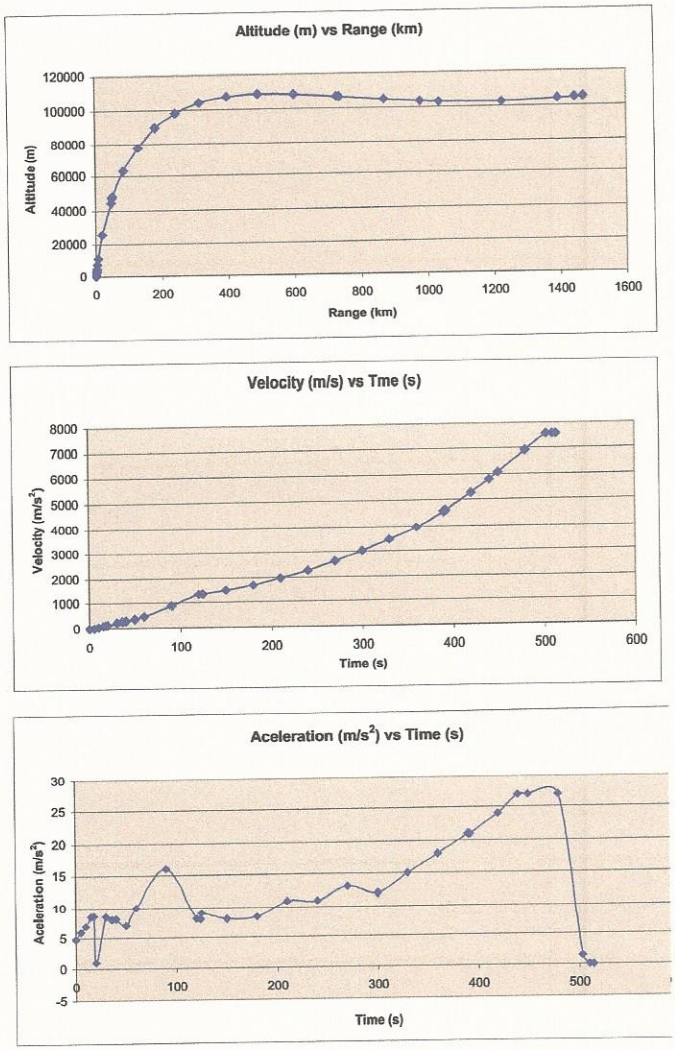

Fig. 1. The main graphs generated: The altitude–range, the velocity-time, and the "sensed" acceleration-time graphs.

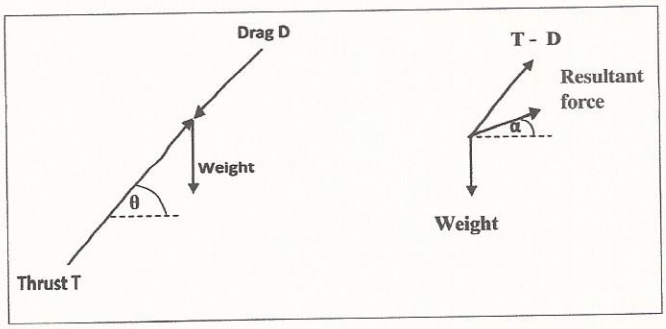

Fig. 2. Force diagram for the motion of the Shuttle.

The second stage of the ascent lasts about 6.5 min. With the solid rocket boosters jettisoned, the shuttle is now powered solely by its three main engines, reaching an altitude of over 104 km and a speed of 7.87 km/s, relative to the center of the Earth. (See altitude-range graph in Fig. 1). The three main engines, attached to the rear of the orbiter, continue to fire until about 8.5 min after liftoff. As the main engine completes its burn, the mass of the shuttle has decreased so much that the engines are throttled back to limit vehicle acceleration to $3g$, necessary to maintain a safe and comfortable ride for the astronauts (see velocity-time and acceleration-time graphs in Fig. 1).

Finally, about 8.5 min after takeoff, the shuttle's engines shut down and the external fuel tank is jettisoned from the shuttle. At this time, the shuttle is traveling at about 8.0 km (5 miles) a second and the orbiter, with a mass of 118,000 kg (260,000 lb), is the last shuttle component that will orbit the Earth. Note that only about 7% of the original mass is left at the end of our description of the launch trajectory journey, when $t = 514$ s.

The motion of the shuttle

Using the data given by NASA of the predicted flight of the STS 119 flight, we can apply elementary physics and mathematics to understand the kinematics and dynamics of the launch. We begin with the description of the physics of the shuttle's motion as a function of time along the path of ascent. For each second we were given the following information: altitude (m); range (km); velocity (m/s); inertial velocity (m/s, relative to the center of the Earth); pitch angle (PA) θ(deg); vertical velocity (m/s); thrust (N); and "drag" or pressure of the atmosphere (N/m^2).

We have added another parameter, the pitch angle (θ), which is the angle that the shuttle makes as measured from the horizontal at a given time. The angle α described determines the tangent to the trajectory, or the direction of the motion of the shuttle at any given time, and is mostly different from the pitch angle. When the shuttle begins its lift, these two angles are almost equal (90° each). During the flight they deviate slightly, meaning that the shuttle is not parallel to its motion. For example, by $t = 480$ s, the angle α is close to 0° but the pitch angle is 17° (see Figs. 2 and 3).

For kinematics:

The above information allows us to calculate:

1. The angle α.
2. The horizontal velocity of the shuttle at any time t.
3. The acceleration of the shuttle in the x and y directions, that is, the horizontal direction and the vertical direction at given time, downrange.
4. The total acceleration on the shuttle.

This will constitute the content of Table I, which is essentially kinematics based on the data given by NASA. Next we

will look at the dynamics of the trajectory and calculate the quantities listed below. We wish to know how well the laws of dynamics (essentially Newton's second law) can account for the kinematic results.

First, there will be a general discussion of how this is done and then we will illustrate the physics for three chosen times. The following will be calculated, using dynamics:

1. The unbalanced force acting on the shuttle.
2. The vertical and horizontal acceleration components of the shuttle.
3. The total acceleration of the shuttle.
4. The centripetal acceleration of the shuttle for high velocities (relative to the center of the Earth).
5. The acceleration "felt" by the astronauts (dynamics).

These calculations will be applied to three times: **Time 1:** Just as the shuttle lifts off the launch pad, $t = 0$; **Time 2**: When air drag is maximum, t = 60; and **Time 3:** When the thrust is lowered, just before main engines cut off (MECO), $t = 480$ s. Note: Our values for the acceleration were calculated for every second, based on the NASA data. The reader should refer to Table I (Kinematics) and Table II (Dynamics) on the previous pages while reading the next section.

Descriptions of the three times

1. **The angle α:** The angle of the tangent of the motion, or simply the direction of motion of center gravity of the shuttle, can be found by calculating the arctan of the vertical velocity divided by the horizontal velocity:

$$\alpha = \arctan(v_y/v_x)$$

2. **The unbalanced force acting on the shuttle at any time:** The net force **F** acting on the shuttle is given by the vector equation

$$\mathbf{F} = T + \mathbf{D} + m\mathbf{g},$$

where T is the thrust produced by the engines of the shuttle and **D** is the total air resistance on the shuttle, given by **pA**, (drag, in Newtons) and $m\mathbf{g}$ is the weight. The thrust (N) and drag per unit area **p** (N/m^2) at time t are given in the table. We will illustrate this when we describe the physics of the second position, when $t = 60$ s.

3. **The vertical and horizontal accelerations components of the shuttle:** The x and y components of the unbalanced force then are

$$\mathbf{F}_x = (\mathbf{T} - \mathbf{D})\cos\theta \quad \text{and} \quad \mathbf{F}_y = (\mathbf{T} - \mathbf{D})\sin\theta - m\mathbf{g},$$

where θ is the pitch angle, the angle between the shuttle and the vertical at a given time.

According to Newton's second law, then we get:

$$a_x = (\mathbf{T} - \mathbf{D})\cos\theta / m$$

and

$$a_y = [(T - D)\sin\theta - m\mathbf{g}] / m$$

4. **The acceleration of the shuttle:** The acceleration can be found by using Pythagora's theorem:

$$a = (a_x^2 + a_y^2)^{1/2}$$

5. **The centripetal acceleration of the shuttle (relative to the center of the Earth):**

When the shuttle reaches an altitude of about 10 km, the centripetal acceleration on the shuttle becomes significant. To determine the magnitude of the centripetal acceleration, we have to use the inertial velocity of the shuttle, that is, the velocity relative to the center of the Earth. Before launch, the shuttle already has a velocity of about 408 m/s east, in the direction of the latitude of 28.6°N. You can easily show that the rotation of the Earth here is 408 m/s east.

We will say that when the centripetal acceleration is 0.1g or larger, it becomes significant. At about $t = 210$ s the centripetal acceleration is about 0.81 m/s^2. So after this time this effect must be taken into account.

The centripetal acceleration is given by:

$$a_c = v^2 / R$$

where $\mathbf{R} = R_E + H$ and **v** is the inertial velocity **VI** as recorded in Table II. R_E = radius of the Earth, about 6.37 x 10^6 m, and H is the altitude of the shuttle in meters.

6. **The acceleration, as found in the NASA data:** You may have noticed that when comparing the accelerations calculated (Table II) and those given by NASA, the accelerations are different. The reason for that is that NASA's acceleration is not the acceleration that acts on the shuttle but the acceleration "sensed" or "felt" by the astronauts. For example, for $t = 5$ s, our acceleration is 6.2 m/s^2 and NASA's is 1.6g, or about 16 m/s^2. Note also that the acceleration given for the very start of the lift is 0.4g. This may be due to the fact that the negative altitude number of -7 m , or -24 ft (see Table I), is a reference to an "idealized geodetic surface." According to our communication with NASA, the shuttle's center of gravity is below this imaginary surface when it is sitting on the pad.

To calculate the acceleration "sensed" is complicated by the fact that the shuttle has a pitch angle at times significantly less than 90° and even more tricky when we enter the region after $t = 300$ s, when the centripetal acceleration has a significant effect.

The following may clarify the idea of "sensed" acceleration: When sitting on the surface of the Earth the acceleration is zero, but the sensation is 1g, whereas in free-fall acceleration the sensation is 0g. Thus, we can say that

$$a_{sy} = a_y + g \text{ (seen as a vector equation).}$$

The acceleration could be measured by a spring scale placed under the astronaut, that is, "sensed" acceleration is related to normal force.

We will now suggest a formula for the acceleration "sensed" by the astronauts and then test it for the three positions we want to investigate. Let us call acceleration "sensed" a_s, which has an x component and a y component. Clearly, the x component is simply

$$a_{sx} = a_x$$

and $a_{sy} = a_y + g + a_c$

(understood as a vector equation), where $g = 9.8$ m/s^2 and $a_c = (VI)^2 / R$. Therefore the acceleration "sensed" is given by $a_s = (a_x^2 + a_{sy}^2)^{1/2}$.

Discussion of the three positions of the trajectory

Time 1, $t = 0$. The shuttle is resting on the platform and all the engines are fired, producing a thrust of 3.02×10^7 N after less than a second. The thrust is much larger than the weight (2.04×10^7 N) of the shuttle and therefore the shuttle begins to ascend. The force diagram here is very simple and the acceleration at that "moment" is given by

$$a = (T - mg)/m = (3.02 \times 10^7 - 2.04 \times 10^7)/(2.04 \times 10^4 \text{ kg}) = 4.8 \text{ m/s}^2$$

This is about 0.5g. In the NASA spreadsheet we read 1.5g. How was this figure obtained?

The acceleration "sensed" by the astronauts can be calculated using the formula suggested earlier. Prior to ascent, the astronauts "feel" the Earth's gravity and, according to the equivalence principle of inertial and gravitational masses, the effect is the same as if the shuttle were accelerating in gravity-free space at 9.8 m/s^2.

Upon launch we only have an a_y component and the total "sensed" acceleration is

$$a_{sy} = a_y + g + a_c = a_y + g - 0 = 4.8 + 9.8 - 0 = 15.6 \text{ m/s}^2 = \text{about } 1.5g.$$

(See Tables I and II).

Time 2, $t = 60$ s. This situation is a little more complicated. The shuttle is climbing in a curve, the pitch angle θ is 59°, and there is now a significant x component of the thrust. Another complication is that we now have maximum air resistance of about 18% of the thrust. We have estimated the effective shuttle area to be 167 m^2.

$A_{eff} = 167$ m^2
$m = 1.38 \times 10^6$ kg
$mg = 1.35 \times 10^7$ N
$T = 3.16 \times 10^7$ N
$p = 35059$ N/m^2
$D = pA = 5.85 \times 10^6$ N

Using equations in section 3 and 4 we find that the x and y components of the accelerations are $a_y = 6.23$ m/s^2 and $a_x = 9.62$ m/s^2. The directly calculated acceleration (that is, the acceleration on the shuttle) then would be $a = (a_y^2 + a_x^2)^{1/2} = 11.4$ m/s^2. The "sensed" acceleration can be obtained this way:

Since $a_{sy} = a_y + g + (VI)^2/R = (6.23 + 9.81 + 0)$ m/s^2,

then $a_{sy} = 15.3$ m/s^2

so that $a_s = (a_{sy}^2 + a_x^2)^{1/2} = 18.1$ m/s^2, or about 1.9g.

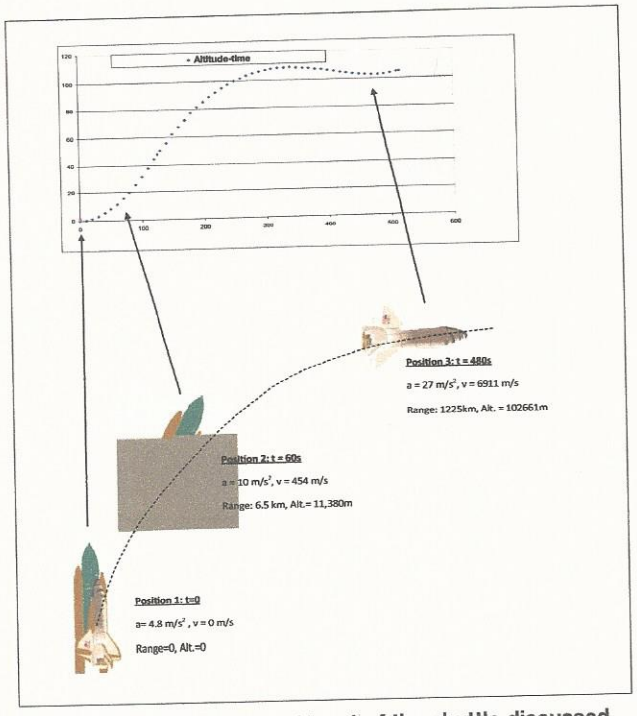

Fig. 3. The three times (positions) of the shuttle discussed.

The acceleration reported by NASA for this position is 2.0 g.

In which direction is the shuttle moving? Earlier we argued that $\alpha = \arctan(v_y / v_x)$. Substituting the values, taken from Table I, we get

$\alpha = \arctan(363/272) = 53°$.

The shuttle at $t = 60$ s then is pointing at about 59° (angle θ) from the horizontal, but the motion is tangent to the curve at 53° (angle α).

Time 3, $t = 480$ s. The shuttle (orbiter plus the large tank) is pointing at a pitch angle of 17°, but moving almost horizontally at 7204 m/s (inertial velocity) and at a high acceleration. Therefore, the angle α is close to zero and the air drag is negligible.

$T = 4.20 \times 10^6$ N
$m = 1.75 \times 10^5$ kg
$VI = 7204$ m/s

The horizontal acceleration is

$a_x = T_x/m$

and $T_x = T \cos 17° = 4.20 \times 10^6 \cos 17° = 4.02 \times 106$ N.

Therefore, $a_x = (4.02 \times 10^6)/(1.75 \times 10^5 \text{ m/s}^2) = 23 \text{ m/s}^2$.

The vertical acceleration is

$a_y = (T_y - mg + mv^2/R)/m = [T_y - m(g - v^2/R]/m$.

Note that at this high velocity the centripetal acceleration becomes a factor. For v we use the VI value of 7204 m/s. Clearly, when $v^2/R = g$, the astronauts are in microgravity

Then $T_y = 4.20 \times 10^6$ N

and $a_y = [4.20 \times 10^6 - 1.75 \times 10^5(9.7 - 8.1)]/ 1.75 \times 10^5$.
Therefore $a_y = 1.6\ \text{m/s}^2$.

The acceleration on the shuttle then is

$$a = (a_y^2 + a_x^2)^{1/2} = (232 + 1.6^2)^{1/2} = 23.2\ \text{m/s}^2 = 2.4g.$$

NASA has an acceleration of $2.9g$.

One could discuss the reason for this difference. For example, one wonders about the accuracy of the pitch angle given for this position. Note that the shuttle is accelerating somewhat vertically at this point, as you can see in Table I.

Conclusion

We have devised a large number of additional problems that may challenge students, from very basic problems on thrust, acceleration, terminal velocity, longitude, and latitude, to advanced problems on Coriolis acceleration and the use of the rocket equation. A guided approach to solve these problems can be found on the website http://www.Arthur Stinner.com. Our main objective in this article is to give physics teachers of secondary schools and colleges a good basis from which to present the launch of the space shuttle, in whole or in selected parts. The concepts and the level of the mathematics required to follow the arguments should be accessible to all physics teachers. The challenge of the physics instructor then is to find ways to present and discuss the ascent of the space shuttle in a comprehensible form that is appropriate to the students' mathematical and conceptual understanding. This is a rich context, and an example of a *large-context problem*, that will engage the attention of all students and may clear up many of the common misconceptions held about the flight of the space shuttle.

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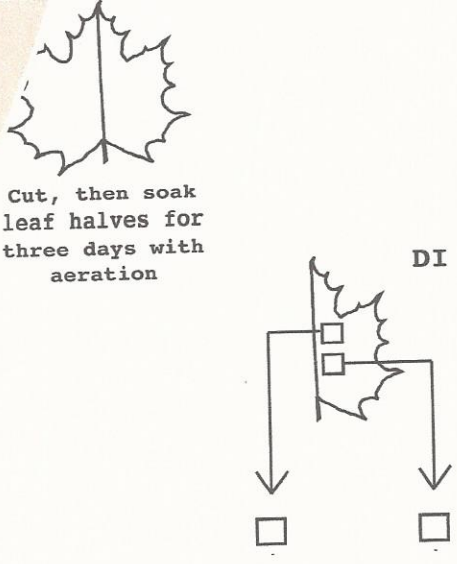
INQUIRY & INVESTIGATION

Teaching Basic Lab Skills Using Diverse Microbial Communities in a Biologically Relevant Context



JOANNA S. BROOKE, PHILLIP E. FUNK, MARGARET E. SILLIKER, TIMOTHY C. SPARKES

Abstract

We present a laboratory-based exercise that is used to teach basic lab skills (e.g., aseptic technique and enumeration) using naturally occurring microbial communities in a real biological context. Students examine the colonization by microbial communities of leaves that fall into streams. Leaf decomposition reflects enzymatic activity by microorganisms such as aquatic fungi and bacteria and maceration by invertebrate shredders. The microorganisms help facilitate the cycling of nutrients and energy in the stream's ecosystem. This exercise effectively teaches students to use lab skills to quantify microorganisms found in nature, investigates groups of microorganisms involved in leaf degradation in streams, and stimulates interest in both microbiology and ecology.

Key Words: *Microbial communities; microbiology lab skills; fungi; cellulose-degrading microbes.*

Traditionally, introductory laboratory courses that use microbiological techniques have a medical focus and tend to use pure cultures to teach basic lab skills (Leboffe & Pierce, 2006). Consequently, students get comparatively little exposure to the dynamics of microbial communities, especially in natural biological contexts. However, microbial species often live in complex multispecies communities in both medical and environmental contexts. This laboratory exercise provides students the opportunity to learn basic lab skills while working with diverse microbial communities. Specifically, students examine the colonization of leaf material in streams by naturally occurring communities of microorganisms. This colonization plays a significant role in ecosystem dynamics because it facilitates energy flow and nutrient cycling in streams (Graça, 1993).

Microbial species often live in complex multispecies communities in both medical and environmental contexts.

When leaves first enter streams they undergo leaching that releases dissolved organic and soluble inorganic materials from them (Webster & Benfield, 1986). The leaves are then colonized by multiple species of bacteria and fungi, often forming microbial biofilms (Bärlocher & Kendrick, 1975; Suberkropp & Klug, 1976; Graça, 1993). Biofilms, which are common in nature, are microbial communities covered in exopolysaccharide material; they are often visible as slimy films on wet surfaces (e.g., on wet rock surfaces near the stream's edge; Atlas & Bartha, 1998). Biofilms form as a sucession of different organisms colonize the leaf-litter surface. Within hours of falling into the stream, leaf-litter particles are colonized by bacteria, and other groups of microorganisms appear later. Temperature and other environmental factors influence the rate at which the leaf litter is colonized (Atlas & Bartha, 1998).

Microorganisms colonizing leaf litter use enzymes to break down complex molecules in the leaf, such as cellulose, chitin, and lignins (Webster & Benfield, 1986). Bacteria involved in leaf decomposition include the Actinomycetes (e.g., *Streptomyces*, *Nocardioides*, *Pseudonocardia*, *Nocardia*, and *Micromonospora*) and bacteria from the *Cytophaga-Flavobacterium-Bacteroidetes* group (Wohl & McArthur, 1998; Lydell et al., 2004). Fungi involved in leaf decomposition include aquatic hyphomycetes such as *Clavariopsis aquatica*, *Tricellula aquatica*, *Tripospermum camelopardus*, and *Gyoerffyella rotula* (Descals, 2005; Gulis et al., 2005). These microorganisms play a critical role in the degradation of leaf material by both digesting the leaf matter and increasing the palatability of the leaf material to macroinvertebrates (e.g., isopods and amphipods; Webster & Benfield, 1986). In addition, these microorganisms produce biomass that is consumed by other organisms in the community. Thus, microbial colonization facilitates the decomposition of leaf material and provides food for other organisms within the ecosystem.

In the exercise presented here, students measure colonization of leaf material by both bacteria and fungi during the first 3 days of leaf submersion using serial dilution, aseptic technique, bacterial plate spreading, and both fungal and bacterial staining to quantify microbial colonization of leaf material. This exercise can be completed in two lab sessions, is relatively inexpensive, and does not require any prior experience with microbiological techniques. In addition, both qualitative and quantitative approaches can be used to describe the data, which gives instructors the opportunity to modify the exercise according to the statistical expertise of the students.

To date, we have used a somewhat recipe-based approach to run this exercise. Here, we introduce a more inquiry-based approach, in which students are given the opportunity to generate new hypotheses and design experiments after completing the initial experiment (see Discussion). It may also be possible to modify the experiment so that a more inquiry-based approach is used for the entire exercise. For example,

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the instructor could provide the students with the relevant background information on the biology of the system, describe the materials that will be available (i.e., presoaked leaves, stream water, etc.), then ask the students to generate testable hypotheses and workable experimental designs. Alternatively, the students could be provided with the experimental design and asked to generate their own flow chart that summarizes the design (see Figure 1 for an example).

○ Experimental Procedure

The students are placed into groups of two to four and asked to collaborate on the assignment. The procedure is summarized in Figure 1. Unless otherwise stated, all chemicals can be obtained from Fisher Scientific. The following is a detailed description of the exercise.

Leaves should be obtained during the fall as soon after abscission as possible. In our experiments we have used maple leaves (*Acer* spp.) collected within a couple of days of falling. The leaves can be autoclaved (121°C, 25 minutes, dry cycle) to kill any microorganisms that may be present. The autoclaving process uses steam at high temperature and pressure, and as a result, the leaves will be fairly brittle but will remain intact when handled with care. Several layers of leaves separated by parchment paper can be autoclaved at once, then allowed to air dry overnight before being frozen at −20°C. Stacks of individual leaves, separated by parchment paper, are placed in clean brown paper bags and frozen until use.

Three days before the first lab session, complete leaves should be cut into two halves. Leaves are cut along the midvein, rather than using separate leaves, to avoid potentially confounding effects associated with preexisting variation in individual leaves. Each leaf half is assigned to one of two containers (e.g., round plastic containers, 18 cm diameter, 8 cm height). These containers are partially filled (~400 mL) with distilled water or stream water and the leaf halves are completely submerged in the water. Once the leaf halves are in the containers, a piece of 1-mm mesh (30 × 30 cm section of screen mesh) is placed over each container so that the middle region of the mesh is submerged in the water. For the stream-water treatment, detritus (leaf material and twigs) and sediment collected from the stream are laid on the mesh so that the microorganisms present in the sample are in proximity to the experimental leaf. Microorganisms (bacteria and fungal spores) from the stream water and detritus will then colonize the leaf material. For the distilled-water treatment, no additional material is placed on the mesh. The leaf halves are held in these containers for 3 days at room temperature and the water is aerated using an air pump (available from a pet supplier).

During the first lab session, the students use sterile forceps, gloves, and scissors to cut two squares (1 × 1 cm) from each leaf half (see Figure 1). To minimize error associated with cutting the squares, we provide the students sterile mesh squares (1 × 1 cm of 1-mm mesh) that can be placed on the leaf to guide the cutting. Two leaf squares are needed for each treatment (distilled vs. stream water). One square will be used to measure fungal colonization and the other will be used to measure bacterial colonization.

Fungal Colonization

During the first lab session, the students mount leaf squares in a few drops of lactophenol cotton blue stain (20 mL phenol [Sigma-Aldrich, no. P9346], 20 mL lactic acid [Sigma-Aldrich, no. W261106], 40 mL glycerine [Sigma-Aldrich, no. S362158], 0.05 g aniline blue [Sigma-Aldrich, no. 415049], and 20 mL distilled water, following Hanlin & Ulloa, 1988) and quickly pass the slide through the flame of an alcohol lamp twice to set the stain. After cooling, a cover-slip is placed over the stained leaf. The students examine the squares using standard compound light microscopes at 40× magnification. The students observe 10 fields of view and record the presence (+) or absence (−) of fungi in a data sheet (Figure 2A). The fields of view are observed systematically in three rows of three or four fields, moving in a left to right direction, to avoid recounting any leaf regions. Fungal colonization can be identified because fungal cells (hyphae) stain a deep blue. We have found that it is helpful to set up demonstration microscopes of stained leaves inoculated with fungi, to help the students distinguish between the stain and stained fungal tissue. Commercial preparations of lactophenol cotton blue are also available (Fisher Scientific, no. R40028).

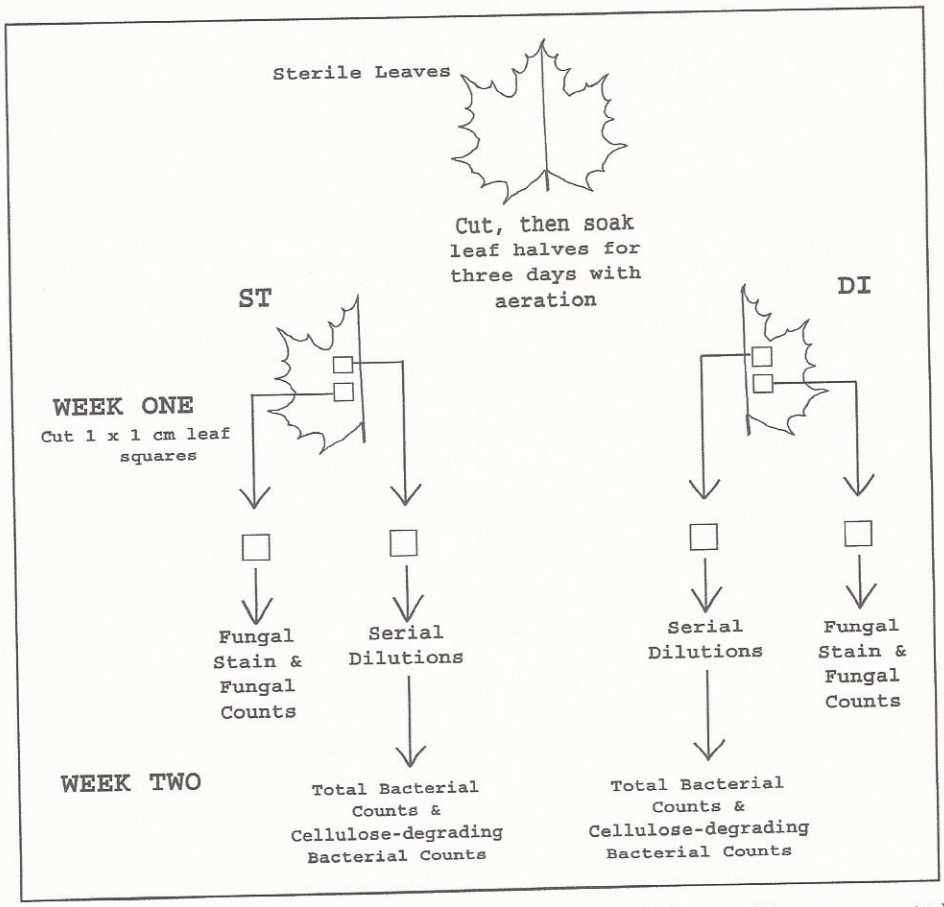

Figure 1. A flow chart of the laboratory exercise (DI = distilled water, ST = stream water).

Bacterial Colonization (Total Bacteria & Cellulose-Degrading Bacteria)

Prior to the first lab session, carboxymethylcellulose agar plates should be prepared (12 per student group) according to the following recipe to make 3 L of agar (120 plates, for a class of 30 students): 15.0 g carboxymethylcellulose, 3.0 g $NaNO_3$, 3.0 g K_2HPO_4, 3.0 g KCl, 1.5 g $MgSO_4$, 1.5 g yeast extract, 3.0 g glucose, 51.0 g agar, and 3 L water (Apun, 1995). This medium is used to detect cellulose-degrading bacteria. The carboxymethylcellulose can be obtained from ICN Biomedicals (no. 101278).

A Fungal Counts (Fields of View)

(Scored as + or – for presence of fungi)

	1	2	3	4	5	6	7	8	9	10	Total
ST											
DI											

B Bacterial (Colony) Counts

	Total Bacteria		Cellulose-Degrading Bacteria	
Dilutions	ST	DI	ST	DI
10^{-2}				
Mean				
10^{-3}				
Mean				
10^{-4}				
Mean				
10^{-5}				
Mean				

Figure 2. Sample data sheet for fungal and bacterial (colony) counts. **(A)** Students observe 10 systematically chosen fields of view using a light microscope (40×) and record the presence (+) or absence (–) of fungi for each observation. **(B)** Students count the total number of bacterial colonies and the number of cellulose-degrading colonies on each agar plate at each dilution of sample (DI = distilled water, ST = stream water).

Students typically work in groups of three for this exercise. They must be careful to practice sterile technique when handling the leaf squares and preparing the serial dilutions. During the first lab session, the students use a sterile pestle to grind the leaf square in 1 mL sterile distilled water for 2 minutes at room temperature. Volumes of the leaf extract are then used to prepare serial dilutions (10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5}) of the extract. Using sterile pipette tips, the entire ground leaf suspension is then transferred to a bottle containing 99 mL sterile water and thoroughly mixed, forming a 10^{-2} dilution. One milliliter of the 10^{-2} dilution is transferred to a fresh tube with 9 mL of sterile water and mixed, forming a 10^{-3} dilution. Further serial dilutions of 10^{-4} and 10^{-5} are prepared by transferring 1 mL of the 10^{-3} and 10^{-4} dilutions, respectively, into fresh tubes with 9 mL of sterile water. Throughout the preparation of the dilutions, the students should flame the mouth of the tube before and after adding the leaf suspension (unless using plasticware).

Carboxymethylcellulose agar plates are inoculated with 100 µL of one of the four suspensions (10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}). The suspension should be carefully spread over the entire surface of the agar plate with a "hockey stick" spreader that has been sterilized by dipping in ethanol and flaming. A diagram of this spread-plate setup can be found in a standard microbiology laboratory manual (e.g., Cappuccino & Sherman, 2002). If one wishes to avoid the use of ethanol and flame, disposable sterile spreaders can also be used (Remel, no. R4853000). Three plates are used for each dilution to provide replicate measures. The plates are then incubated in an inverted position (to avoid condensation effects) for 1 week at room temperature.

During the second lab session, the students record the number of bacterial colonies (using the data sheet provided in Figure 2B) then calculate the average colony number per sample for each dilution (using counts obtained from the three replicate plates). If the number of colonies present on a plate is sufficiently high that enumeration is not possible, they should be scored as TNTC (too numerous to count).

Once the colony counts have been completed, the students quantify the number of cellulose-degrading bacteria present by flooding the surface of the agar plates with 10 mL of 1 mg/mL Congo red stain (ICN Biomedicals, no. 15071125) for 15 minutes and then flooding them with 10 mL of 1 M NaCl for 10–15 minutes. Colonies of cellulose-degrading bacteria are identified by the appearance of a clear zone around the colony that results from digestion of the carboxymethylcellulose by the bacteria. The students record the number of cellulose-degrading colonies per plate and calculate the average colony number per sample for each dilution (using the three replicate samples).

Sample Data & Analysis

A sample data set for the exercise is available on request. Using both qualitative and quantitative measures, it is apparent that leaves exposed to stream water were colonized rapidly by fungi and bacteria whereas leaves exposed to distilled water were not. In addition, cellulose-degrading bacteria were common on the stream-water leaves, accounting for approximately 17–20% of the bacterial community present, but were rarely present on the distilled-water leaves. The results demonstrate clearly that leaf material was colonized by a diverse community of microorganisms (fungi, cellulose-degrading bacteria, and non-cellulose-degrading bacteria) and that organisms were abundant in the stream water (and detritus) obtained from the local stream.

In addition to demonstrating microbial colonization and community diversity, the students can also gain valuable experience in both data analysis and interpretation. For example, the students can be encouraged to run their own statistical analysis. For the quantitative data, a paired t-test could be used on both the fungal and bacterial counts (using Microsoft Excel). These analyses would be paired because each student group worked with two halves of the same leaf, which controls for potential effects of preexisting variation in leaf quality.

The students can also be asked to discuss how using different leaves (rather than leaf halves) could have influenced the results. Finally, the students can be asked to determine which dilution provided the best estimate of bacterial colonization. In our case, the 10^{-2} dilution was excluded because most of the plates were scored as TNTC. We would also recommend excluding the 10^{-5} dilution because colony counts were low and, hence, more prone to sampling error than dilutions with large colony counts. In our example, the remaining dilutions (10^{-3} and 10^{-4}) could be used to estimate population size. These values yielded estimates of 7.2×10^6 (obtained from the 10^{-3} leaf dilution) and 21×10^6 (obtained from the 10^{-4} leaf dilution) bacterial colony-forming units per milliliter (average $\approx 14 \times 10^6$). Consistent with this interpretation, microbiologists often adopt a "30–300" rule, whereby counts are made only on plates with more than 30 but less than 300 colonies. By plating and counting the four dilutions presented here, students will obtain a conceptual understanding of a rule that may at first seem somewhat arbitrary.

Discussion & Conclusions

In performing this laboratory exercise, students should acquire basic lab skills while simultaneously gaining a greater appreciation for the critical role that microorganisms play in both energy flow and nutrient cycling in nature. Using this starting point, students can be encouraged to think about other ways that microbial communities influence relationships in nature. For example, the gastrointestinal tract of humans is home to a vast community of microorganisms (Hooper & Gordon, 2001), and diverse communities of bacteria and fungi are used in the management of wastewater to break down the suspended organic matter, dissolved organic material, and inorganic compounds in sewage (Atlas & Bartha, 1998). These microbial activities contribute to the release of mineral nutrients and organic humus into the water supply. Students could also be asked to consider the impact of microbial communities on health and disease in humans. For example, diverse communities of bacteria contribute to plaque and tooth decay, and bacteria that naturally occur on the body (normal flora) help prevent infection by pathogenic bacteria (Madigan et al., 2000).

This laboratory exercise gives students a relatively simple glimpse into a complex world of microorganisms that may at first seem somewhat intimidating. Ideally, this type of exposure will spark sufficient interest in the students that they will be motivated to learn the more technical skills required to study microbial community dynamics at an advanced level. This exercise is also beneficial because it can be used to emphasize the integrative nature of modern science. For example, leaf degradation in streams is dependent on both the colonization of leaf material by microorganisms (microbiology and microbial ecology) and the feeding behavior of macroinvertebrates (animal behavior and behavioral ecology). The combined actions of these organisms result in the release of energy and nutrients (aquatic biology and ecosystem ecology), which helps to sustain a diverse stream community (population ecology and community ecology). Students could be encouraged to explore these areas as well as the connections between areas by posing questions and designing experiments that follow from the exercise presented here.

For example, students might use the basic skills they have acquired in the experiment to identify the relative contributions of the different sources of microorganisms to the microbial community that colonized the leaves. In the exercise presented here, stream water, detritus, and sediment were included as potential sources of microorganisms. Students could design a relatively simple experiment in which they expose fresh leaves to various combinations of these sources and then quantify the microbial colonization associated with each source.

Students could also take a more behavioral approach by examining the effects of microbial colonization on the feeding behavior of macroinvertebrates. Previous studies have shown that microbial colonization of leaf material influences the feeding behavior of macroinvertebrates (Graça, 1993). Specifically, colonized leaves are more palatable than uncolonized leaves and are preferred over uncolonized leaves in diet preference trials (Graça, 1993). Students could be encouraged to run an experiment in which they expose macroinvertebrates (e.g., aquatic isopods or amphipods) to colonized and uncolonized leaves and then record feeding activity on the different leaf types (for examples of this type of experiment, see Canhoto et al., 2005; Sparkes et al., 2008).

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How To Teach Math With LEGOs

By Katie Lepi on September 7, 2014

Using Legos in the classroom is not a new concept at all. There are so many different classroom applications for the popular brightly colored bricks, and despite the myriad of uses, the go-to task for Legos is most often math. The handy little nubs sitting atop the bricks offer a chance to teach things like area and perimeter, the different colors lend themselves well to fractions.

The handy infographic below takes a look at different ways to use fractions to teach math. The visual aspect is pretty handy – you can clearly see how your students will be able to group and divide the blocks to grasp the concepts in a fun way. Do you have other math-specific ways you've employed Legos in the classroom? Share your awesome ideas with the Edudemic community by