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Update on Directed STEM Lessons for Developing Student Interest in Agriculture: A Work in Progress

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Abstract

Agricultural & Biological Engineering faculty have been concerned for several years regarding the lack of interest in high school students in good-paying technology-oriented careers in agriculture and have developed some academic modules to hopefully stimulate some interest in these areas. Through a USDA-NIFA grant, the authors have developed three secondary level curricular programs designed to provide an overview of the modern technical elements of the agricultural industry. Classroom activities for five weeks of daily one hour contact time were developed for an introduction to aerial drones, vehicle balance, and robotics with agriculture. These modules were designed for testing in a local high school agriculture classroom. Bloom's taxonomy was used as a framework, inspiration, and guide to develop the modules as a best curricular practice aligned with recruiting. This paper will present multiple examples of lesson components and how they fit into the remember, understand, apply, analyze, evaluate, and create framework. The planned implementation schedule and the difficulties encountered thus far will be described, and the details of the overall program assessment will be provided.

Keywords

agricultural instruction; hands-on learning; high school; lesson plans; STEM

Introduction

Purdue University researchers, concerned about the general lack of interest in agricultural careers by high school students, set about to provide some stimulating curricular content for high school agriculture teachers, emphasizing the modern, technology-infused components of the industry and resulting in a series of Agriculture-based STEM lessons. The background and global objectives of the researchers were covered previously [1], but in summary, it was hoped that some stimulating technology lessons provided during the career formative years of high school might convince more students to select an agricultural vocation as being leading edge and worthy of consideration as a potential career option. The current employment plight within agriculture is severe and contains a double-edged sword [2]. Jobs in the agricultural world are perceived as low class and menial, but the technological knowledge necessary to operate and maintain some of the new equipment requires the ability for an employee to learn new skills and be able to work with computerized processes [3]. While there does not seem to be a recent comprehensive study of the Agricultural Engineering field like the one conducted in 2000 by Henry et al. [4], information from the National Center for Educational Statistics indicated that general bachelor's degrees in agriculture have declined 10% from their peak [5], reducing the pool of skilled workers at the entry level and exacerbating the labor problem. Employers are being squeezed by the need for skilled help and the perception of agricultural work as low value. Declining farm populations and increasing farm sizes have also contributed to the decline in agricultural workers [6], and the phenomena is international in nature [7]. Agriculture has traditionally drawn both its management and labor from the pool of agrarian people having experience with agriculture.

If previous agricultural experience represents a minimum criterion for consideration in agricultural employment, the potential pool of recruitable employees for the industry becomes unacceptably small. It is imperative that the industry broaden its pool of potential applicants. At the same time, the complexity of the equipment in use has grown incredibly within a single generation [8]. The addition of complex software, electronics, robotics, seed and spray optimization, UAV crop scouting, Big Data, CAN-BUS vehicular controllers, global positioning, autosteering, and vehicle autonomy will necessitate an educated and educatable agricultural workforce [9]. In order to provide Bachelor degree level employees that can supervise and teach other employees about the emerging electronic revolution in agriculture, collegiate programs, like Agricultural Systems Management, must bring-in students with less of a connection to the industry. That means being competitive with other potential disciplines when recruiting students. The developed curriculum is designed to plant an interest in an agriculture-based STEM career by exposing students to some of the more interesting elements of modern agricultural software and hardware to show them that they don't have to come from a farm to be interested in agriculturally-based careers. Three modules of five weeks duration for a one credit high school level agriculture class were developed by collegiate agricultural engineering and technology faculty members to showcase innovative modern agricultural tools with the intention of exposing students to the bigger picture of UAV data collection, off-road vehicle safety, and agricultural robotics. These modules were selected for their ability to engage with students by building upon prior knowledge, introducing them to typical problems within the field that they can engage with in a hands-on manner, and then present the area as having a significant challenge in the field that they could have a positive impact upon, if they were so engaged [10], [11]. Both of these motivational factors are felt to be attractive in aiding career selection for the current generation.

The balance of this paper will provide a more detailed overview of the developed overall program, including its overarching vision and module execution commonalities. The paper will attempt to demonstrate that the convenience for the front-line instructor was a strong driver during the learning module's development. Implementation of the program has been delayed repeatedly due to the lack of a qualified instructor within the local career center originally chosen for implementation, but the module developers believe that this has allowed more time to craft a better educational product. A discussion has been provided about the original plan, as well as the problems that have been encountered along the way. Program modifications and the alpha test plan moving forward are also discussed. The plan for assessment, collection of feedback, and improvement of the educational efficacy of the modules will be described. The conclusions will provide the module developer's thoughts on the overall experience to date.

Program Overview

The three modules of the agriculture-based STEM lessons for high school students were designed and planned using the principles of Bloom's educational taxonomy for inspiration [12], [13], [14]. The six-part learning efficacy processes of remember, understand, apply, analyze, evaluate, and create have been applied across the three modules during their development. These modules were intended for formal use within upper division high school agricultural curriculum, following appropriate basic mathematics and science classes. Material from the vehicle balance module will be used to illustrate the curricular developments explored in this paper. This module was selected for highlighting and presentation within this paper as the most comprehensive and ready for external review, as well as being the one which best illustrated the use of modern technology to solve a problem which has existed throughout the mechanization of agriculture. Figure 1 reveals college students in 1905 at Purdue checking their hand calculations of draft on a hitching system using a physical simulator [15]. High school students using this module will utilize computers and software, along with physical experiments, to master the same problem. Modern software, in the form of spreadsheets and pre-written applications, has become ubiquitous throughout modern agriculture, and it is vital that students realize the applicability of computer-based applications in solving individual problems and managing the overall enterprise of growing the world's food, fuel, and fiber. The intent of the researchers across these modules was not to demonstrate direct use of presented materials within day-to-day agricultural operations, so much as it was to show the possibilities of advanced technology within the field, demonstrating the evolution of agricultural practices within the modern world to include elements of the information revolution.

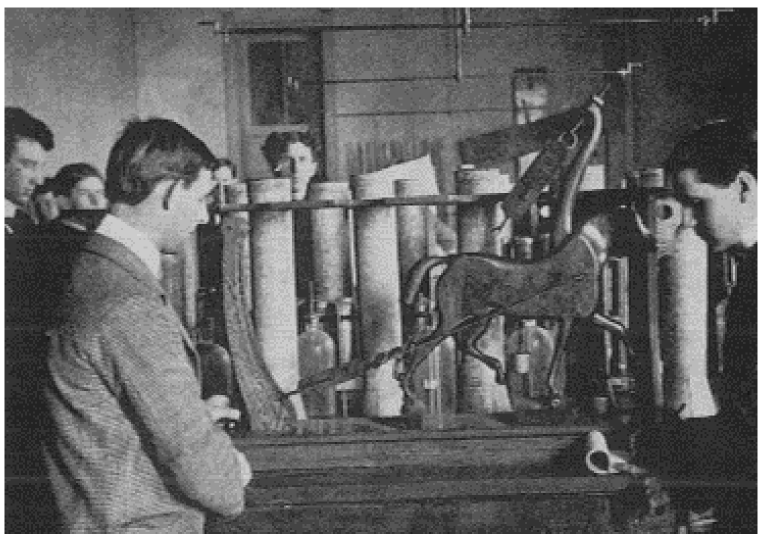


Figure 1 – Purdue University students using a physical hitching simulator to check hand calculations for implement coupling [15] (Knoll, 1963).

The global learning standards or educational outcomes for the vehicle balance module are presented in Table 1. These were developed from a general discussion by the lesson researchers with the other members of the Agricultural Systems Management (ASM) and Agricultural Machinery and Systems Engineering (AMSE) faculty about the general ideas and concepts that should be included in any vehicle balance module. They do not necessarily conform to the 'approved' Bloom vocabulary, so much as they simply convey the general areas of material to be covered for a beginning level of mastery. Additionally, the list was trimmed to exclusively include only vehicle balance elements during the development of the course, as it became apparent that the initial vision for material coverage was too ambitious. As initially conceived, the planned content was too large for the available high school interval of 50 *min* of daily classes and was reduced to an appropriate length, focusing primarily on the balance and ground contact features of off-road vehicles. An ASM instructor, who primarily teaches freshmen and not associated with the development of the modules, was recruited to review the modules initially and help adjust the rigor of the lessons to an appropriate level.

Table 1 – Off-road vehicle balance module educational outcomes.

1) Understand the concept of the torque, levers, and summing moments.
2) Understand the concept of force vectors and the summing of forces.
3) Be able to calculate a center of mass.
4) Be able to calculate the normal reaction forces on a stationary, static vehicle.
5) Be able to calculate the forces on a vehicle under load in a pseudo-dynamic state with a fixed hitch position.
6) Be able to calculate the forces on a vehicle under load in a pseudo-dynamic state with a varying hitch length and height.
7) Be able to calculate the forces on a vehicle under load in a pseudo-dynamic state with various ballast amount and positions.

The general plan for the lessons was that review and recollection of basic knowledge would be guided by the classroom instructor through the initial portion of a 'lecture' phase of each day's course material. The instructor would attempt to tie the fundamental concepts to previously provided knowledge from other classes, provide a review, and describe the relevance to the problem at hand. During the second portion of the lecture period, the instructor will work some specific example problems associated with the daily concept. In general, multiple problems are provided from a couple different viewpoints to give the instructor the opportunity to utilize the material from different perspectives. Students are then provided with a worksheet exercise that moves through the next phases of Bloom's learning activities.

During the laboratory portion of the exercise, the students will apply the processes just demonstrated by the instructor on their own or in teams to the same style of problems, just presented as numerical variants. The students will then further apply the concepts under study to slight conceptual additions or a more complex alternative of the problem, through hand calculations. Many of the lab modules transition into using a provided computer program at this point, which is used to elevate the students' use of the concepts into the analysis stage, using a spreadsheet focused on the specific lesson. These students are essentially being asked to run numerical experiments, after demonstrating that they can successfully apply the overall concepts and be freed from performing the arithmetic in the calculations. Advancing to this stage should allow the students to concentrate on seeing trends and ramifications of variations in the problem, instead of performing perfect mathematics.

The next level of learning mastery will be provided in the final problems of the lab worksheets, where students are asked to make judgment decisions about the ramifications of their specific investigation. Typically, these worksheet questions will ask for the students to evaluate the consequences of the phenomena that they have been investigating or why they believe it to be important. The final creative use element will be accomplished during a separate hands-on, team-based competition, where the students will get to build and modify miniature pulling tractors. The decision-making options provided in the set-up for this event will give the students an opportunity to implement their new knowledge and close the active course learning efforts in a fun, positive manner. Although the basic problem remains the same as studied in an earlier era, today's high school students will be able to use the provided software to explore vastly more scenarios and situations than the previously referenced college students from over a century ago, hopefully moving to a deeper level of understanding through the use of modern technology. Instructors have additionally been provided with three versions of a mid-term assessment and a final assessment. The course developers have also created a pre-course and post-course knowledge level assessment for evaluating the overall efficacy of the completed module's design.

Learning Objectives and Lesson Features

The course definition limited the class admission to upper division high school students with sufficient math and physics background to be able to recognize relevant earlier educational topics appropriate to the overall vehicle balance problem. This module, along with the robotics and UAV modules, would be appropriate material for Indiana high school students in a career and technical education (CTE) program under the Agricultural, Power, Structures, and Technology academic standards content framework, within the Emerging Technologies domain [16]. Individual lessons often begin with 'you should recall from …'. In Figure 2, the slide presented from Lesson 1 lists examples where the student will have encountered the concept previously, relating torque to the twist of an engine flywheel and a screwdriver. Lesson 4 incorporates the definition of a vector, a concept that would have been introduced in previous mathematics classes. Figure 3 shows definition of the vector, listing the key features on an early slide from the lesson. As the lessons progress deeper into the module, the recall portion of the learning process begins to refer to course material covered earlier in the module. Lesson 12 is about the phenomena popularly known as 'weight' transfer, but it references a previous lesson on the distribution of hitch loads in Lesson 10. Figure 4 displays this call-back to a previous in-module concept.

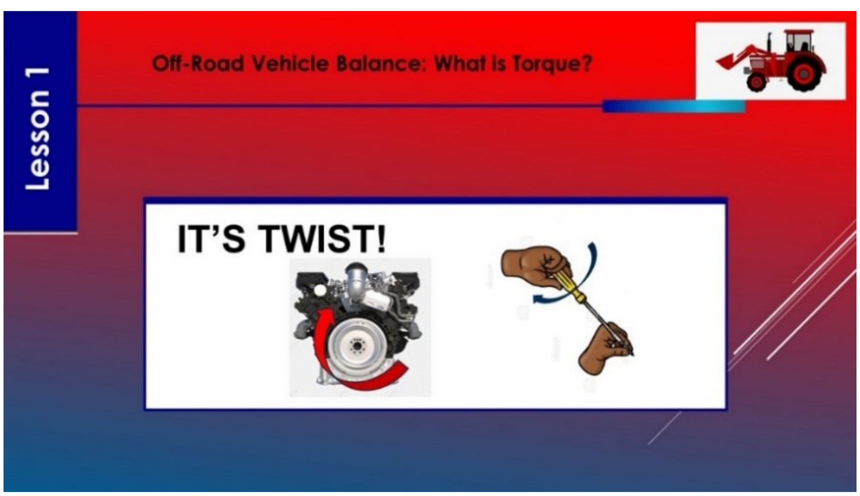


Figure 2 – Knowledge-level instructional slide from the torque lesson in the agricultural-based STEM vehicle balance module.

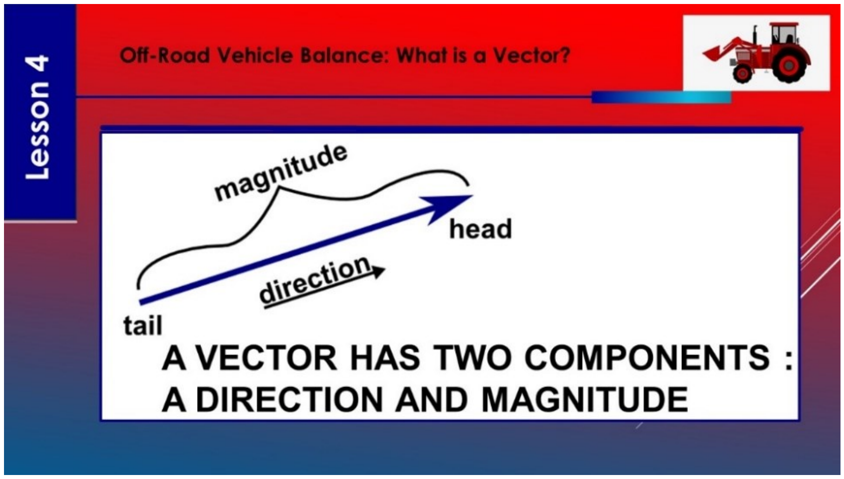


Figure 3 – Knowledge-level instructional slide from the vector lesson in the agricultural-based STEM vehicle balance module.

Figure 4 – Knowledge-level instructional slide from the 'weight' transfer lesson in the agricultural-based STEM vehicle balance module.

The key concept under consideration within each lesson was always described in the comprehension section of each lesson. This piece provided a beginning explanation of how the concept related to the overall topic of vehicle balance. The lesson on levers identified each type of classification and provided the mathematical description of the lever action near a well-detailed drawing of the situation. The slide from Lesson 2 presenting the comprehensive element of Class 1 lever use is shown in Figure 5. Lesson 6 on summing forces provides details on the process involved in combining three three-dimensional vectors into a single force, as shown in Figure 6. Classroom instructors were typically provided with three alternative sets of numerical problem examples for each process expression type of slide. Lesson 14 on the effect of hitch length provided an opportunity to do a comparison of a key value in the overall problem. Figure 7 shows the slide with the presentation of the example, and Figure 8 illustrates the results.

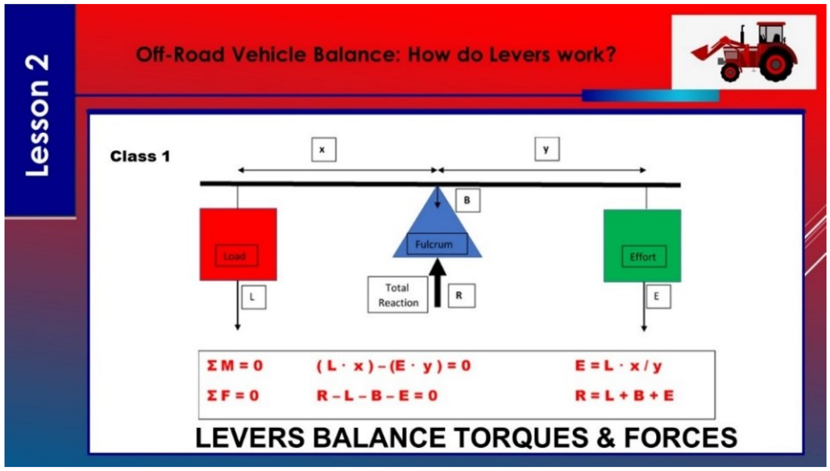


Figure 5 – Comprehension-level instructional slide from the levers lesson in the agricultural-based STEM vehicle balance module.

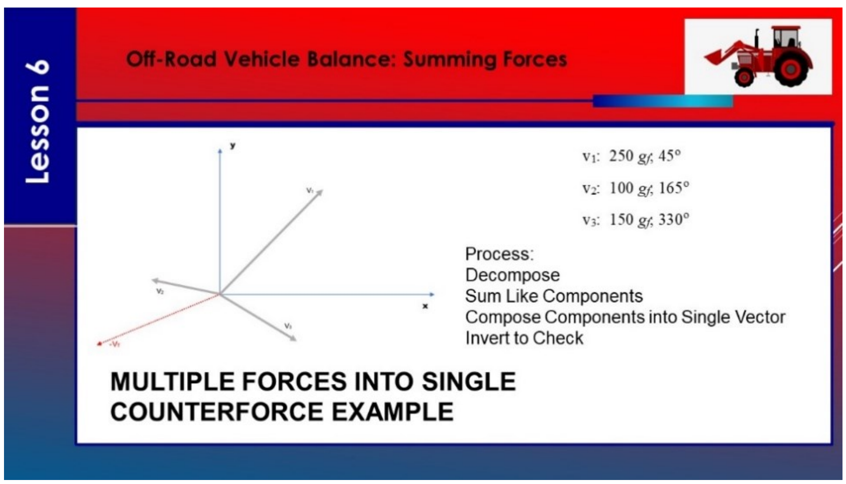


Figure 6 – Comprehension-level instructional slide from the summing forces lesson in the agricultural-based STEM vehicle balance module.

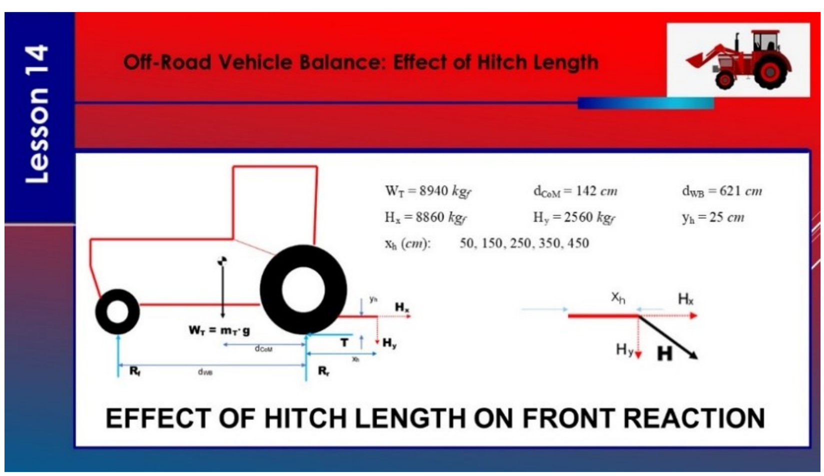


Figure 7 – Comprehension-level instructional slide from the effect of hitch length lesson describing a numerical experiment in the agricultural-based STEM vehicle balance module.

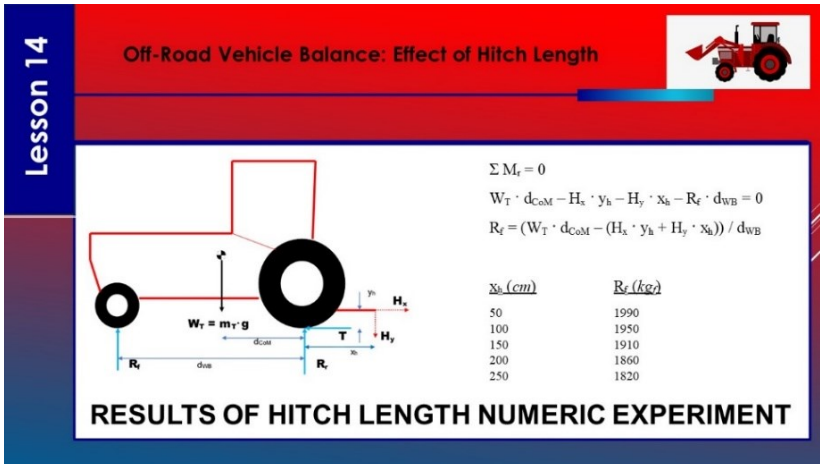


Figure 8 – Comprehension-level instructional slide from the effect of hitch length lesson presenting results from a numerical experiment in the agricultural-based STEM vehicle balance module.

The application phase of knowledge development was provided by a more intensive student utilization of the key concepts presented by the instructor in the first portion of a laboratory worksheet for each lesson. In Lesson 3, students are guided through progressively more complex center of mass calculations, allowing their confidence to build along the way, as they demonstrate a mastery of the concept. Table 2 provides a sample problem, applying the center of mass concept to a large four-wheel drive tractor. The problem copy exhibited is from the Instructor's Key, which provides additional illustrative material for the instructor detailing the problems, as is presented in the corresponding Figure 9 for the four-wheel drive center of mass problem. Lesson 13 on hitch height utilized a similar example of sufficient hand calculations to establish comfort and a mental construct of the newly introduced concept. Having the students employ their basic calculation skills illustrated the need to employ both representational mathematics and practical physics to complete a deeper level of knowledge comprehension. Figure 10 shows the physical set-up of the demonstration problem, and Table 3 presents the formulation of the problem.

Table 2 – Application-level instructor's key worksheet exercise with problem answers from the center of mass lesson in the agricultural-based STEM vehicle balance module.

A large four-wheel drive tractor is nosed into a wall. It has the following components, weights, and distances from the wall (Figure 3C):

Engine	3850 kg_f	1.3 *m*
Front Axle	2890 kg_f	1.5 *m*
Transmission	1860 kg_f	2.1 *m*
Front Frame	5650 kg_f	2.8 *m*
Cab	1150 kg_f	3.5 *m*
Rear Frame	4630 kg_f	4.2 *m*
Rear Axle	2890 kg_f	4.8 *m*
Rear Hitch	3100 kg_f	5.3 *m*

i) $c = \Sigma (W_i \cdot A_i) / \Sigma W_i$ — $c =$ ____3.184____ *m*

ii) Add a Ballast Box to the tractor: 4200 kg_f 0.4 *m*

iii) Calculate new CoM: $c_{ballast} =$ ____2.797____ *m*

iv) Add an implement to the tractor hitch: 6420 kg_f 7.1 *m*

v) Calculate new CoM: $c_{hitched} =$ ____3.551____ *m*

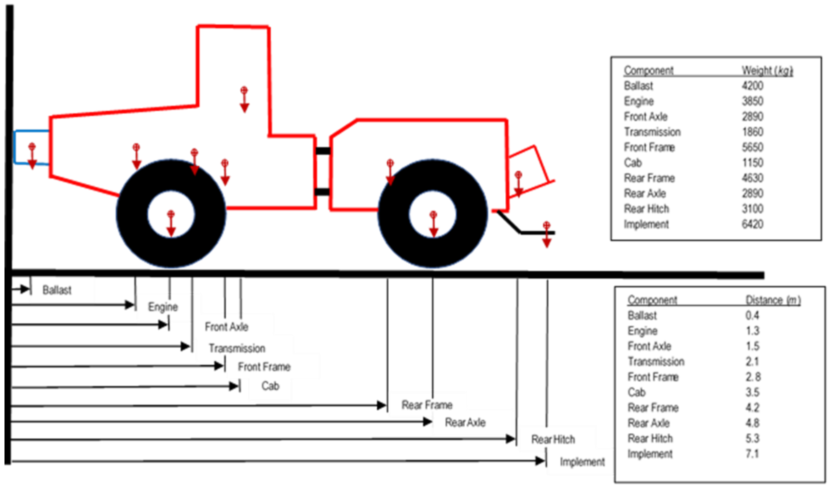
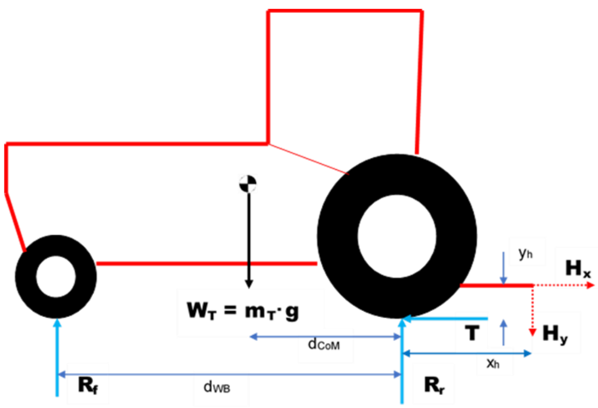


Figure 9 – Application-level supplemental instructor's key drawing (Figure 3C in that document) from the center of mass lesson in the agricultural-based STEM vehicle balance module.



$$R_{f\text{-loss}} = -(H_x \bullet y_h + H_y \bullet x_h) / d_{WB}$$
$$R_{r\text{-gain}} = H_y + (H_x \bullet y_h + H_y \bullet x_h) / d_{WB}$$

Figure 10 – Application-level supplemental drawing from the hitch height lesson in the agricultural-based STEM vehicle balance module.

Table 3 – Application-level instructor's key worksheet exercise with problem answers from the hitch height lesson in the agricultural-based STEM vehicle balance module.

W_T (kg_f)	d_{CoM} (cm)	d_{WB} (cm)	H_x (kg_f)	H_y (kg_f)	x_h (cm)	y_h (cm)	R_f (kg_f)	R_r (kg_f)	$R_{f\text{-loss}}$ (kg_f)	$R_{r\text{-gain}}$ (kg_f
3500	100	300	4500	1500	80	25	392	4608	-775	2275
4500	125	350	4500	1500	80	35	814	5186	-793	2293
5500	150	400	4500	1500	80	45	1256	5744	-806	2306
6500	175	450	4500	1500	80	55	1711	6289	-817	2317
7500	200	500	4500	1500	80	80	2040	6960	-960	2460
5000	115	275	4500	1500	80	105	-64	6564	-2155	3655
6000	145	325	4500	1500	80	115	715	6785	-1962	3462
7000	160	375	4500	1500	80	125	1167	7333	-1820	3320
8000	190	425	4500	1500	80	135	1865	7635	-1712	3212
9000	225	475	4500	1500	80	145	2637	7863	-1626	3126

Student progress toward analysis within the learning process should become deeper and more integrated with higher level thinking skills, as the students progress in each lesson. Computerized tools are provided at this point to complete more extensive calculations and to free students to look at trends and the implications of the factors under examination, by comparing and contrasting different results from the experiments. All software applications were constructed in Excel® (Microsoft, Incorporated; Redmond, Washington) using the recommended five column pedagogical pattern of variable identifier, definition, numeric value, units, and miscellaneous information, including the formulas [17]. In the code for this module, light green boxes represent values for the student to fill-in, and light blue represent computer calculated values. Lesson 5 on decomposing vectors includes a typical Excel spreadsheet for calculation, as shown in Table 4. The corresponding illustrative drawing is provided in Figure 11. Table 5 provides the corresponding computer program for the lesson on reaction forces, while Figure 12 gives the detailed free-body diagram. The computer program for the ballast lesson is shown in Table 6, and Figure 13 gives the associated force diagram. All software sheets were locked and immutable upon distribution, so that the programs could not be corrupted accidentally in use.

Table 4 – Analysis-level provided software from the decomposing vectors lesson in the agricultural-based STEM vehicle balance module.

Off-Road Vehicle Balance: Decomposing Vectors				
Lab #5: Decomposing Vectors Spreadsheet				
©Purdue University Agricultural & Biological Engineering - Bob Stwalley 2023 rms3@purdue.edu				
			User Input Value	
			Calculated Value	
Variable Identifier	Definition	Numeric Value	Units	Miscellaneous
W_T	Total Weight		g_f	
θ	Angle from Origin		^{o}	
W_x	x axis component	0	g_f	$W_T \bullet \cos(\theta)$
W_y	y axis component	0	g_f	$W_T \bullet \sin(\theta)$

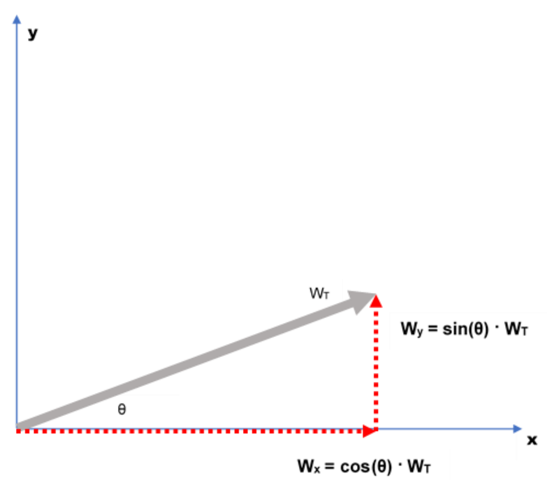


Figure 11 – Figure associated with computer code supplied for analysis-level decomposition of vectors lesson in the agricultural-based STEM vehicle balance module.

Table 5 – Analysis-level provided software from the reaction forces lesson in the agricultural-based STEM vehicle balance module.

Off-Road Vehicle Balance: Reaction Forces				
Lab #7: Reaction Forces Spreadsheet				
©Purdue University Agricultural & Biological Engineering - Bob Stwalley 2023 rms3@purdue.edu				
			User Input Value	
			Calculated Value	
Variable Identifier	Definition	Numeric Value	Units	Miscellaneous
W_T	Weight of Tractor		g_f	
d_{CoM}	Distance from rear axle to CoM		cm	
d_{WB}	Wheel Base		cm	
R_f	Front Reaction Force	#DIV/0!	g_f	$W_T \bullet d_{CoM} / d_{WB}$
R_r	Rear Reaction Force	#DIV/0!	g_f	$W_T - R_f$
$R_f : W_T$	Ratio of Front to Total Forces	#DIV/0!		R_f / W_T

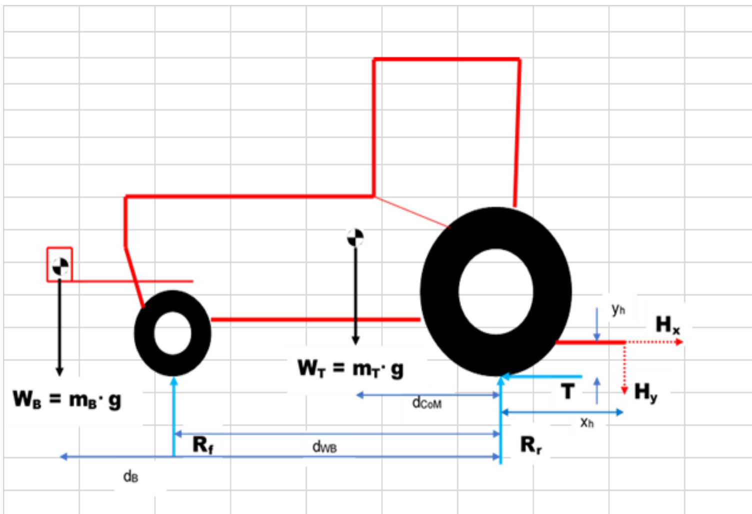


Figure 12 - Figure associated with computer code supplied for analysis-level reaction forces lesson in the agricultural-based STEM vehicle balance module.

Table 6 – Analysis-level provided software from the ballast lesson in the agricultural-based STEM vehicle balance module.

Off-Road Vehicle Balance: Ballast				
Lab #16: Ballast Spreadsheet				
©Purdue University Agricultural & Biological Engineering - Bob Stwalley 2023 rms3@purdue.edu				
			User Input Value	
			Calculated Value	
Variable Identifier	Definition	Numeric Value	Units	Miscellaneous
W_T	Weight of Tractor		g_f	
d_{CoM}	Distance from rear axle to CoM		cm	
d_{WB}	Wheel Base		cm	
H_x	Vehicle Draft		g_f	
H_y	Vehicle Downforce		g_f	
x_h	Hitch Length		cm	
y_h	Hitch Height		cm	
W_B	Weight of Ballast		g_f	
d_B	Distance from rear axle to ballast		cm	
R_f	Front Reaction Force	#DIV/0!	g_f	$((W_T \bullet d_{CoM}) + (W_B \bullet d_B) - (H_x \bullet y_h) - (H_y \bullet x_h)) / d_{WB}$
R_r	Rear Reaction Force	#DIV/0!	g_f	$W_T + W_B + H_y - R_f$
R_f-loss	Front Reaction Loss	#DIV/0!	g_f	- (Hx • yh) - (Hy • xh) / dWB
R_r-gain	Rear Reaction Gain	#DIV/0!	g_f	H_y + ((Hx • yh) + (Hy • xh)) / dWB
$R_f : (W_T + H_y)$	Ratio of Front to Total Forces	#DIV/0!		$R_f / (W_T + W_B + H_y)$

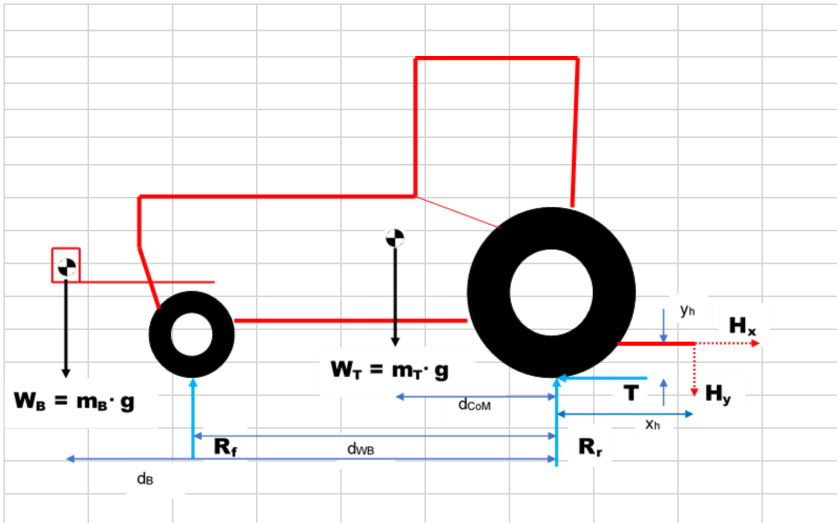


Figure 13 - Figure associated with computer code supplied for analysis-level ballast lesson in the agricultural-based STEM vehicle balance module.

An evaluation phase for each individual lesson concluded the worksheet of the vehicle balance module. The students were asked to evaluate and access 'why' certain outcomes occurred. Unlike the prior analysis phase, which taught interpolation within a concept, this segment of the Bloom taxonomy focused on an interpretation of general factors and an extrapolation of the results outside the defined problem. Table 7 provides evaluation prompts and answers from the Instructor's Key, on measuring reactions in Lesson 8. Students were requested to think about ground/tire interactions in the evaluation piece of Lesson 11 on traction. Table 8 presents those questions. Finally, students are prompted to generalize about the rollover phenomena during the evaluation portion of Lesson 15. Those queries are posted in Table 9.

Table 7 – Evaluation-level questions from the measuring reactions lesson in the agricultural-based STEM vehicle balance module.

Is the tire pressure on the ground uniform across the contact area? Why or why not?
____No, it will vary from high pressure values to pressure at the very edge of contact. Accurate measurement would reveal contour lines of pressure. An accurate weight calculation would require working with very small differential areas.________________

What does a non-centered Center of mass do to the tire reaction forces?
____It changes the reaction forces present on the tires to be non-uniform, concentrating reaction closest to the CoM. Heavy forces will wear tires faster and may make maneuvering awkward.____

Table 8 – Evaluation -level questions from the traction lesson in the agricultural-based STEM vehicle balance module.

Which kind of tire do you predict will wear faster and why: a high fuel economy tire with a low rolling resistance or a high maneuvering ability tire with a high rolling resistance?
___Friction and wear are associated with higher rolling resistances, even though those tires provide the best handling. The tires designed for maneuverability will grind their rubber off into the pavement faster than the high mileage, low resistance tires._______

Why do you want an off-road tire to bulge in contact with the ground?

___The bulge on contact with the ground indicates a low tire pressure, which is how all tractor drive tires are set to run. The bulge increases the contact area with the ground, thereby reducing the soil contact pressure. This reduces soil compaction.____________

Table 9 – Evaluation -level questions from the rollover lesson in the agricultural-based STEM vehicle balance module.

Why are off-road vehicle operations on hillsides dangerous?
___Off-road vehicles, particularly farm tractors, have a high Center of Mass. This reduces the vehicle's ability to operate on an incline, particularly moving parallel to the contours. Less additional tip is needed to enter an unstable situation.____________

Why is a small utility-type tractor problematic when operating under heavy propulsive load?
___Small utility tractors develop outstanding axle torque for their size. It is easy to overload the unit in draft and bring its forward progress to a halt. An improperly-coupled oversized implement can cause rotation at its rear axle and an overturn.

The creation phase of learning for the vehicle balance module was provided by a miniature pulling tractor and classroom contest between the lab teams. It was conducted asynchronously with the other lessons and could be moved within the overall module at the instructor's need. The initial design of the tractor was supplied by Dr. Josh Jackson of the University of Kentucky Biosystems & Agricultural Engineering department. Students were provided sufficient, but minimal, assembly instructions to encourage collaboration and discussion. An example of the instructions is found in Figure 14. Figure 15 shows a global placement example slide for the front axle assembly. Figure 16 lists the bill of material for the same assembly, and Figure 17 provides the necessary tool inventory for the assembly. Figure 18 shows the detailed assembly drawing of the front axle of the pulling tractor. During the creative phase, students will be able to combine individual parts into a larger assembly. They get to organize their work and manage the effort to produce the desired high-quality outcome, simulating the teamwork and professional skills used in the business world [18], [19]. The multiple sub-assemblies are connected into the actual miniature pulling tractor. The contest was meant to add some competitive spirit to the overall activity, but it is well-recognized that the full optimization of the pulling tractor cannot be undertaken in the limited scope of this module. The exercise was intended for the students to enjoy and envision possibilities.

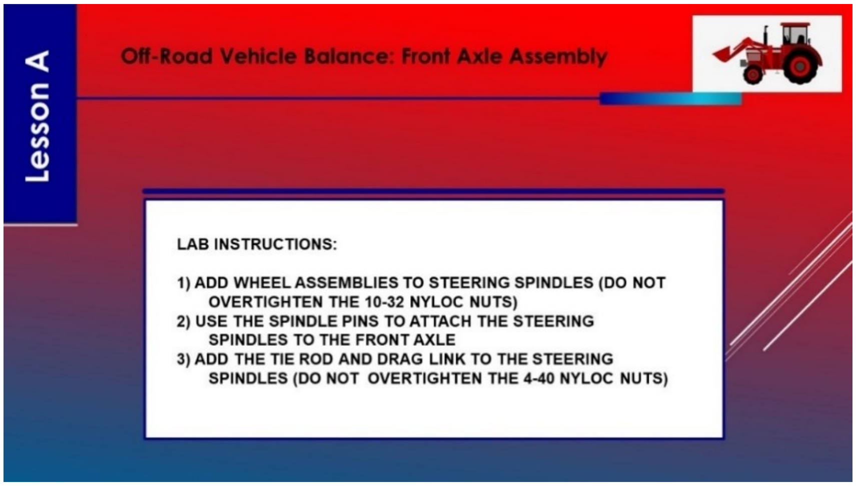


Figure 14 - Slide associated with the instructions for the miniature tractor in the creation-level front axle lesson of the agricultural-based STEM vehicle balance module.

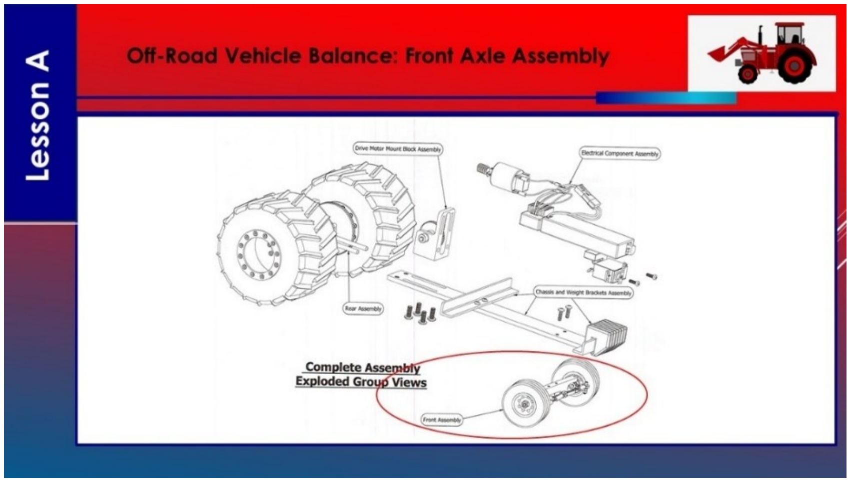


Figure 15 - Slide associated with the global position on the miniature tractor in the creation-level front axle lesson of the agricultural-based STEM vehicle balance module.

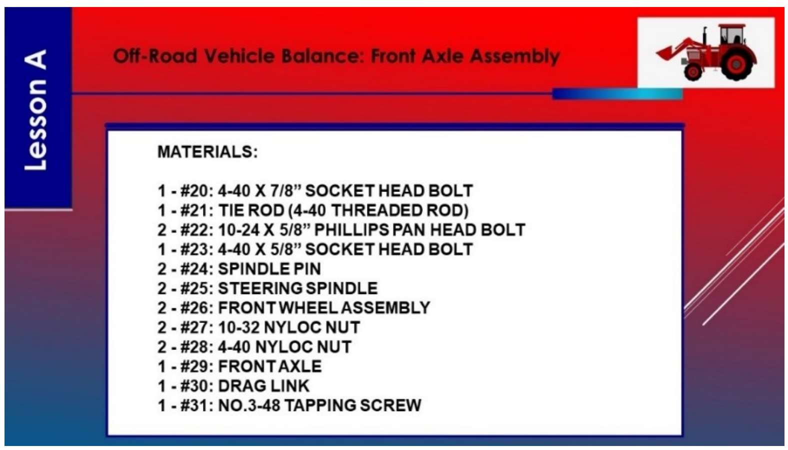


Figure 16 - Slide associated with the front axle bill of material for the miniature tractor in the creation-level front axle lesson of the agricultural-based STEM vehicle balance module.

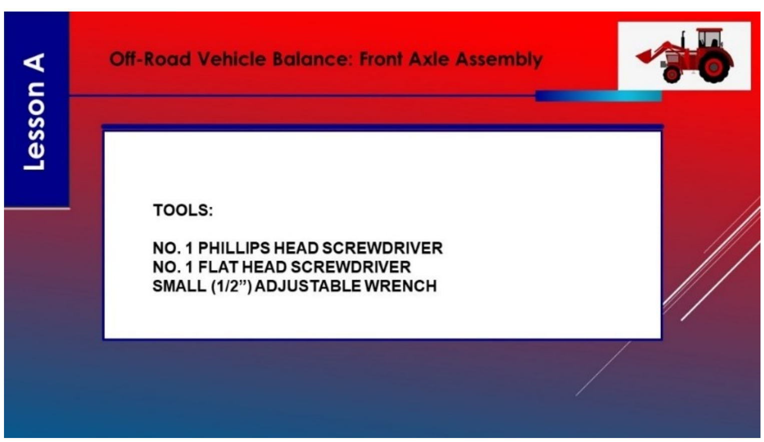


Figure 17 - Slide associated with the tooling needed for the miniature tractor in the creation-level front axle lesson of the agricultural-based STEM vehicle balance module.

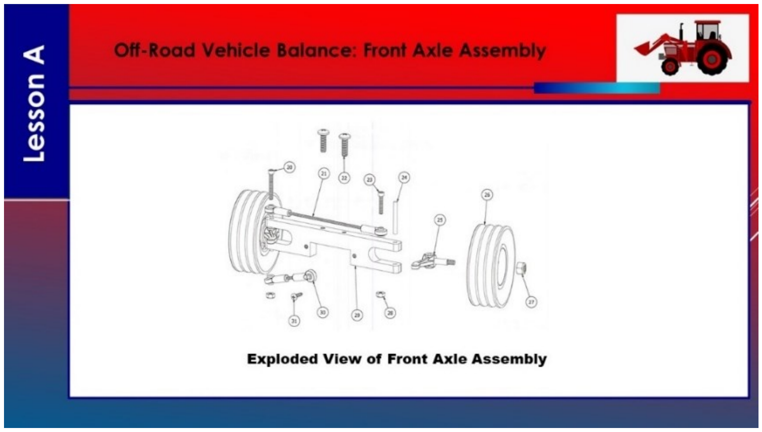


Figure 18 - Slide associated with the front axle detailed assembly of the miniature tractor in the creation-level front axle lesson of the agricultural-based STEM vehicle balance module.

The active learning portions of the vehicle balance module have been constructed around guidelines developed to ensure active engagement with each level within each assignment [20], [21]. The lesson plans feature activities which reference life experiences, have hands-on components, are collaborative, proscribe work with peer team members, and require an application of the knowledge components identified as important and closing the loop on why a skill is important. Students engaged in critical thinking in the 'why does this work' and 'how can I use this' realms are far more likely to retain information longitudinally [12], [13].

Implementation Plan and Difficulties Encountered

The researchers' preliminary plan had been to complete an alpha execution of the new high school STEM-based ag learning modules at the Greater Lafayette Career Academy (GLCA) [22], beginning with the fall 2023 term. The GLCA is a newly-organized combined secondary public education entity in Tippecanoe County, Indiana functioning as a CTE center. The participating public school corporations are Lafayette School Corporation (LSC), Tippecanoe School Corporation (TSC), West Lafayette Community School Corporation (WLCSC), and Benton Community School Corporation (BCSC). High school students from all four corporations may partake in the career center's offerings, and TSC manages the entity for the group. LSC and TSC contribute the largest numbers of students to the center's enrollment.

The Greater Lafayette community public schools have a long history of collaborative ventures, including a special education cooperative and numerous inter-local cooperation agreements [23], [24]. The founding of the career center was advantageous for all the local school corporations, because it combined the educational operations of career-oriented courses into a central location, freeing significant space within the corporations' existing secondary school buildings throughout the county. This enabled the corporations to absorb their current increase in student populations, without each corporation needing to build new facilities. The existing high schools' trades programs were slated to move in two phases, consolidating their operations into the new center and relinquishing space in the original secondary buildings. Health Sciences, Hospitality Services, and Public Safety coursework moved first, followed by a planned Phase II relocation of the Automotive, Aviation, Construction, Precision Agriculture, and Welding programs. Unfortunately, only a single high school program for agriculture existed in the contributing schools, and the single instructor opted to remain under contract at their original school, instead of moving to the new career center.

This had the unfortunate effect of placing the agriculture program at the CTE into hiatus. It has been extremely difficult to secure a new agriculture instructor. Current data indicates that certified high school agriculture teachers are scarce overall [25], [26], which is also likely contributing to the lack of students interested in agriculture at the collegiate level. The obvious irony of the situation is that an experience designed to stimulate an interest in agricultural careers for students has been held-up by the lack of agricultural professionals teaching high school classes. These newly developed course modules, which should have had their first test utilization in the fall of 2023, will receive a partial utilization of the robotics and off-road vehicle balance modules during the spring of 2024, following TSC's gracious offer to implement the ag STEM lessons at another high school. Feedback interpretation and course improvement will occur during the summer of 2024, following this initial alpha release.

First Use Debrief and Module Assessments

The human subjects work associated with the evaluation of the high school modules was approved under Purdue IRB #2017-1671. The investigation of the efficacy of the agriculture-based STEM lessons will be measured through a fairly standard technique, the difference of a pre- and post-course simple ten question multiple choice evaluation [27], [28], [29], [30]. This technique is well-accepted in educational and social science research, being able to create quantitative information from qualitative assessments across time, in what is known as a matched-pair T-test analysis [31], [32], [33]. The presumed difficulty of the test is the medium range (3/5), the selected level for optimal discrimination of change, based on a limited number of questions and pre-course preparation [34]. Unfortunately, the course development has only just begun. There have been no opportunities to sample the ability of likely students for the course on discrimination questions for the learning efficacy, as is best practice [35]. The experience of the researchers has been used to gauge the initial level of question difficulty, typically reported as the fraction of incorrect results. Future adjustments will be based upon the reaction to the current catalog of questions.

The course efficacy evaluation was developed to be sufficient to show learning retention, but purposely kept short, to not interfere with productive classroom instruction time. The pre-test was intended to be administrated during the first classroom meeting, before any other activities, and the post-test was meant to be given following the comprehensive final examination for the course. There is some evidence to support that students understand the purpose of the bookend exams and attempt to gauge their own net learning [33], [30]. Many appreciate the subject introduction and closure offered by the pre- and post-test exam experiences. Student learning will be inferred from the difference in the individual student's performance across time spent within the learning module. It is well-accepted that this type of testing is conforming in nature, improving the internal validity of discrimination, while reducing the external validity of the experiment outside the educational scenario. There will be no control group of students that are provided the pre-test, uneducated in the subject matter, and then retested later. Additionally, the experimental design does not compensate for the naturally occurring second attempt improvement. Deeper questions, such as what the spread of improvement across the learners is, the population significance level, and were there appropriate knowledge gain at all levels, will need to be deferred until a larger experience base with the course can be established. The aim of this initial experience is to launch the modules and execute a first debug and improvement round, based upon initial exposure of the course to the target market of high school students. The initial statistical research question will therefore be simple in nature, and it will seek to determine if there was an improvement in basic knowledge from the agriculture-related STEM or not, using a dependent samples t-test at the ($p < 0.05$) level:

$$\text{Student's Module Assessment Score: } H_0: S_1 \geq S_2 \quad H_1: S_1 < S_2$$

An instructor briefing session was conducted early during the spring 2024 semester. The robotics learning module was chosen for initial use during the middle six weeks of the term. The vehicle balance module will be used during the last six weeks. Module debriefs with the instructor will be conducted as soon as practical, following the conclusion of the unit. The instructor will correlate the pre- and post-test scores. They will only report anonymized data pairs to the researchers, preserving the students' hidden identities. Incorrect worksheets, difficult lessons, improper time allocation, and unclear lesson exposition will be carefully investigated and repaired before a beta release of the modules is attempted.

Conclusions

Since any intrusion of the real world into the theoretical affects both simple and intricate plans, it should be noted that the delay has had both positive and negative consequences on the module testing. The delay has significantly reduced the window of available time to evaluate the initial product, revise the contents for errata and clarity, and re-release it for use in secondary agriculture programs. These later activities will now likely only occur following the official closure of the federal grant funding the work. On the other hand, the modules are of much higher quality than they were six months previously. The course development effort would appear to conform to the ideal gas law and expand to fill all available schedule holes. Creating an instructor's guide and photographing the exercises located several huge blunders and simplified many instruction sets. The consistency in presentation was maintained throughout, and the number of cross-linkages between lessons was noted as being larger than originally presumed. If a new terminology or process was instituted to improve the lessons, it was changed across the module. The total development time invested to provide solid, engaging lessons for the vehicle balance module was easily over 200 hours. This amount of effort was mirrored by the agricultural robotics and UAV lesson developers. In summary, the following agricultural lesson module design points are worth emphasizing:

- Quality technical course development is time intensive.
- An application of Bloom's taxonomy within the lesson plan provides the best opportunity for long-term knowledge retention from students.
- Progressive activities, that engage students through hands-on practical exercises promote critical thinking and comprehensive understanding.

Overall, the team is pleased with all of the modules from the USDA/NIFA effort. The vehicle balance module as a completed project did become more computer program-oriented than originally planned, at the expense of time for the hands-on tractor contest. However, this also provided some flexibility for high schools unable to support the miniature pulling contest activity. They can just delete the event from the syllabus. The researchers are committed through the re-release phase of development for the modules, following the upgrade from the alpha release. They are currently recruiting high school instructors that could execute a beta round of course releases. As materials are debugged and improved, it is anticipated that the researchers will make them broadly available electronically to all high school agriculture instructors. Additionally, the courses in their finished forms appear to be modular enough to be ported into other on-line media. That possibility will be examined to gain further exposure and distribution for the lessons. Finally, the researchers will continue to report the results of the module evaluations and revisions upon the instruction and recruitment of high school age students into agricultural-based STEM fields.

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