

STEM K-12 Outreach as the Root of Transportation Education: Experiences from the Railway Engineering Field

Transportation Research Record
2019, Vol. 2673(12) 558–569
© National Academy of Sciences:
Transportation Research Board 2019
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/0361198119841564
journals.sagepub.com/home/trr


C. Tyler Dick¹, Pasi Lautala², and Bryan W. Schlake³

Abstract

Demand for graduates with rail transportation expertise remains strong in North America, particularly in engineering and technical fields. Over the past decade, various activities by the American Railway Engineering and Maintenance-of-way Association and rail-focused University Transportation Centers have slowly re-established a railway engineering academic community. Railway courses are now offered at two dozen universities in the United States (U.S.), and, for the first time in decades, several universities offer specific degrees in railway engineering. Despite this progress, challenges remain, such as raising student awareness of rail industry career paths. Since most railway engineering courses are senior-level electives, many students are already committed to other engineering disciplines before they are exposed to railway concepts. To raise student interest in rail courses and satisfy industry demands for internships, students must be introduced to railway concepts before they decide on the direction of their studies. One approach to directing more rail-aware students into engineering programs is rail-themed outreach to K-12 students. Railways still hold a fascination for many young people as complex, multi-disciplinary systems, and numerous interesting science, technology, engineering, and math (STEM) concepts can be demonstrated through the lens of railway transportation. Interactive rail-themed classroom activities can illustrate STEM topics while highlighting rail career opportunities and reinforcing railway transportation. This paper reviews rail-themed K-12 STEM outreach activities being undertaken by universities and the strong partnerships between industry and academia required to grow future generations of railway professionals.

The North American railway network provides safe, reliable, and efficient movement of people and products that drives economic development. A well-functioning rail transportation system is ultimately dependent on a supply of skilled rail transportation leaders to plan, design, operate, maintain, and manage the rail system of the future. However, only a small number of rail academic programs in North America are engaged in rail-related research and teaching courses to educate the next generation of railway professionals (1). Over the past decade, collaboration between academia and industry has succeeded in expanding the number of university courses on railroad topics (2). For the first time in several generations, university students in the United States (U.S.) can complete specific minors and full undergraduate and graduate programs leading to railway transportation engineering degrees. This progress has resulted in new challenges, namely recruiting a sufficient number of undergraduate students with an interest in rail to sustain new education programs and meet industry demand for student interns. Meeting this demand requires further

collaboration between industry and academia to raise student awareness of rail industry career paths at an earlier stage of their education. One approach to directing more rail-aware students into engineering programs is rail-themed outreach to K-12 students. This paper briefly describes how the railway engineering field arrived at this situation and reviews recently expanded railway engineering educational opportunities. The paper concentrates on rail-themed K-12 science, technology, engineering, and math (STEM) outreach activities being undertaken by universities, and the strong partnerships

¹Rail Transportation and Engineering Center – RailTEC, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL

²Rail Transportation Program, Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI

³Rail Transportation Engineering Program, Penn State Altoona, Altoona, PA

Corresponding Author:

C. Tyler Dick, ctdick@illinois.edu

between industry and academia required to grow future generations of railway professionals.

Decline of Railway Education in Academia

During the early 20th century, railroad engineering and economics comprised significant portions of university curricula in civil, mechanical, and electrical engineering. At this time, the historical relationship between higher education and North American railroads reached its peak (3). A major force in the development of these engineering disciplines within universities had been the need for trained engineering professionals to expand the North American rail network.

When railways were rapidly surpassed by airlines and highways as preferred passenger transportation modes in the U.S. during the early 1950s, the university–railway relationship began to weaken. As passenger rail service began to be discontinued on many lines, fewer students used railway transportation or were exposed to active rail construction projects (4). While railways were viewed as a mature technology with a shrinking network, the rapid expansion of highway and airport infrastructure presented research challenges that, coupled with liberal funding to address them, quickly drew the interest of transportation academics. Universities eliminated railway engineering programs, faculty adjusted their university transportation courses, and students altered their career plans accordingly. Between 1956 and 1964, only 0.3% of the graduates from the civil engineering program at the University of Illinois at Urbana-Champaign (UIUC) went on to employment in the rail industry; a substantial decline compared with the rate of over 10% between 1910 and 1920 (5).

As railways consolidated, abandoned thousands of miles of track, deferred maintenance, and curtailed investment in research and development during the 1960s and 1970s, the relationship between universities and railways continued to decline. Deregulated in 1980, railways cut costs by reducing employment and outsourcing many engineering functions to consultants. By the 1990s, most engineering graduates would obtain their degrees without any exposure to railroads. By the start of the 21st century, less than 15% of North American universities included railway engineering as a topic in general transportation courses and less than 3% offered a separate course on railway engineering (6). In 2005, a survey of 500 engineers with 5 years or less of rail industry experience revealed that 84% had not received any college exposure to rail topics (6). Interestingly, even in Europe, which is perceived to have a stronger railway academic community than North America, varying faculty interest in rail has resulted in gaps in university railway curricula (7).

Rejuvenation of the Rail Industry and Demand for Graduates

As early as 1980, it was recognized that the current level of railway engineering course content would not sustain long-term demand for railway engineering professionals (8). However, it would take several decades, a dramatic increase in traffic, constrained capacity, changing demographics, and renewed interest in passenger rail for the issue to come to the forefront.

During the time when university railway educational activities dropped to their lowest point, North American freight railroads were in a period of growth and expansion with record traffic levels driven by containerized freight and high demand for bulk commodities such as coal. Between 1980 and 2008, Class I railroad revenue ton-miles would nearly double and the railroad share of all intercity freight ton-miles would increase significantly to 42% (9). Higher axle loads to increase productivity and constrained capacity on key mainline corridors led railroads to invest hundreds of billions in capital improvement projects (10). Studies of future traffic growth have indicated that over \$100 billion in further improvements will be required to meet demand through 2035 (11). Additionally, freight railroads have increased hiring in recent years. From 2009 to 2015, U.S. Class I railroads increased average annual employment by about 13% (~20,000 jobs) (12).

This same period has been marked by renewed interest in expansion of passenger rail service and employment. Between 2002 and 2013, as various states developed regional intercity passenger corridors, Amtrak ridership increased by over 50% and Amtrak set a new annual ridership record 10 out of 11 years (13). Between 1997 and 2012, commuter rail ridership increased by 49% and eight new commuter rail systems have inaugurated service since 2004 (14). While employment in heavy passenger rail has remained relatively constant over the last 20 years, employment in commuter rail has grown by an average of 2.1% annually, and the light rail workforce has grown by 8.3% since 1993 (15). Planning and design of proposed high-speed rail systems has slowly created additional demand for railway engineering talent while simultaneously capturing the imagination of many students (16).

The railway capacity projects required to support growing freight and passenger traffic created a sudden increase in demand for railway engineering professionals that academia was not equipped to meet (17). For the rail industry, the general demographic trend of an aging transportation workforce was compounded by the decades-long lack of railway engineering course content at the university level (18). As the senior project managers who had railroad engineering in their academic programs continue to retire, the railroad industry faces the

prospect of all future rail design being inherited by a young generation of designers who have little, if any, academic background and domain knowledge of railroads (19).

Re-emergence of Railway Engineering Education and New Degree Programs

The resurgence of railway transportation, and in particular the purchase of BNSF Railway by Berkshire Hathaway and introduction of the Obama administration "Vision for High-Speed Rail", both in 2009, did not go unnoticed by academia. The American Railway Engineering and Maintenance-of-Way Association (AREMA) Education and Training Committee ("Committee 24") survey of civil and transportation engineering professors found interest in incorporating railroad engineering material into current transportation courses and development of new courses devoted to the subject (20). The survey also found that a lack of railway research funding, connections to railway industry professionals, and suitable teaching materials were significant barriers to expanding railway engineering activity within academia.

To help faculty overcome these obstacles, the concept of an innovative industry-sponsored event to provide interested faculty with railway engineering course materials and connections to industry professionals was developed. Held every two years since 2008, the Railway Engineering Education Symposium (REES) brings engineering professors together with peers already specializing in railway engineering and with railway engineering professionals who work for railroads, governments, consultants, and research facilities. The symposium provides the professors with lecture materials for incorporation into transportation classes. Through presentations and discussions, they learn basic railroad engineering concepts that enable them to use the lecture materials effectively. REES also exposes the professors to various facets of the railway industry, including its recruitment and research needs. While the original objective of REES was to encourage participation by professors with no previous background in rail transportation, more recent events have seen a return of professors from earlier events who are eager to continue the expansion of their knowledge in the field.

As a direct result of REES, railway engineering courses have been modified, enhanced or added at two dozen universities in the U.S. The development of railway educational and research activities at four of these universities, Rose-Hulman Institute of Technology, University of Nevada Las Vegas, University of South Carolina, and Villanova University, were highlighted in the 2013 paper by Lautala et al. (21).

The recent expansion of railway engineering course offerings for undergraduate and graduate students was aided by the formation of the National University Rail Center (NURail), a U.S. DOT University Transportation Center, in 2012. NURail grants have provided critical resources to expand rail transportation education within the partnering universities. During the first three years of the NURail Center, between 2012 and 2015, the number of rail-focused courses at NURail partner institutions increased by 90% to a total of 34 rail-related courses, including new classes developed under NURail, such as Advanced Track Engineering and Railway Terminal Design & Operations at the UIUC, and Railroad Track Engineering at the University of Illinois-Chicago. The reach of these courses has also expanded as the number of online courses increased from three to ten over the same period.

The number of rail-focused courses has also allowed for the development of specialized programs in railway transportation and engineering and, for the first time in decades, several universities offer specific degrees in railway engineering:

- Penn State Altoona is currently the only institution in the U.S. offering a specific Bachelor of Science (B.S.) degree in Rail Transportation Engineering (RTE). Located in Altoona, Pennsylvania, the RTE program is building upon a strong history of railroad research, testing, and education pioneered by the Pennsylvania Railroad. The RTE program provides a core civil engineering curriculum along with rail-specific courses covering disciplines such as railroad track infrastructure, mechanical department functions, signaling, and train operations. In 2015, Penn State Altoona graduated their first class of RTE students. In 2017, the RTE program was formally accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).
- In Fall 2016, Michigan Technological University (Michigan Tech) introduced a Minor in Rail Transportation. The eligible courses for the minor were selected based on the input from the Michigan Tech Rail Transportation Advisory Board (RTAB). Designed to be multi-disciplinary in nature, the coursework combines general railroad engineering and transportation logistics courses with discipline-specific courses considered relevant to graduates seeking careers in the rail industry.
- In Fall 2018, the UIUC will inaugurate a new Master of Engineering (M.Eng.) in Railway Engineering degree program. The three-semester

interdisciplinary program is targeted at students who want to gain greater depth and breadth in railway, civil, mechanical, and electrical engineering topics through additional rail-focused coursework prior to embarking on rail industry careers. Although Illinois has been engaged in railway education activities continuously since 1898, the M.Eng. program will mark the first time students can formally pursue a specific railway engineering degree at Illinois since 1947. At that time, because of declining interest, the separate Railway Engineering Department was moved into the Department of Civil Engineering and the railway educational program became an area of specialization within the undergraduate and graduate civil engineering degree programs.

- Other institutions offering multiple railway courses, such as the University of South Carolina, have developed graduate certificate programs in railroads that serve as a pathway to full Master of Science programs with a focus on railway engineering topics.

The emergence of rail-focused elective courses and new degree programs in railway engineering at multiple institutions has resulted in a new challenge: recruiting sufficient numbers of interested students to sustain the investments in faculty and other resources required to offer rail-focused courses and degree programs. It is also raising a renewed importance in developing robust linkages between the universities and industry so students in these programs can secure career opportunities after their studies.

Recruiting Students to the Academic Railway Industry Pathway

While railways still fascinate many young people and youth continue to be involved in model railroading and other railway enthusiast hobby activities, only a very small minority of students seek out specific academic programs in railway engineering based on their personal interests. Unfortunately, the railroad industry is rarely considered as a potential future career by today's youth, and heavy competition from other industries may hinder the recruitment of even those individuals who have expressed interest in railways. The small number of institutions offering rail-focused courses presents another obstacle to students with a strong interest in rail. Without a local university offering courses in railway transportation, students face the choice of paying higher out-of-state tuition to pursue their railway interests, or settling for a local program that is more general and does not provide them with the rail domain knowledge,

industry contacts, and railway internships critical to securing a position in the railway engineering field after graduation.

As early as the late 1950s, it was recognized that declining use of passenger rail service and an overall decrease in railway employment in the U.S. would diminish the number of youth inspired to pursue railway careers by vacation travel and family connections to railway employees (4). These trends continue to the present day. With little railway industry outreach to youth at the K-12 level, the vast majority of incoming engineering students enter university without any awareness of potential careers in the rail industry.

Students most often receive their first formal exposure to railway concepts through lectures on introductory transportation engineering courses at the junior and senior levels. These lectures are key to sparking student interest in the railway field and, where available, leading students to enroll in senior-level elective courses specifically on railway topics. However, faculty engaged in delivering these senior-level rail-focused courses often observe that, by the time most students are exposed to railway engineering concepts during senior year, it is frequently too late to steer them into careers in the rail industry. Based on course evaluations and experiences with students over multiple academic years, lack of student exposure to railway concepts until senior year is one of several factors that affects their likelihood of enrolling in rail-focused courses or pursuing a career in the rail industry. Some of the common challenges in guiding students to railway-related studies and careers include:

- **Senior year is too late.** By the first semester of senior year, many students have already accepted job offers with, or feel committed to, other employers in engineering disciplines. Students often feel a loyalty to, or have already accepted positions with, employers through internships following sophomore and junior years but prior to them becoming aware of railway career opportunities.
- **Limited elective flexibility.** To obtain an accredited degree, engineering students must complete numerous courses on a range of engineering fundamentals that ultimately support specialized rail topics. Rail-focused electives must compete with other interesting specialized courses for a limited number of slots in the students' academic plan. By senior year, students are often committed to certain academic program plans with limited flexibility to enroll in one or more rail-focused electives.
- **Fear of specialization.** Students often express a concern that they do not want to become "too

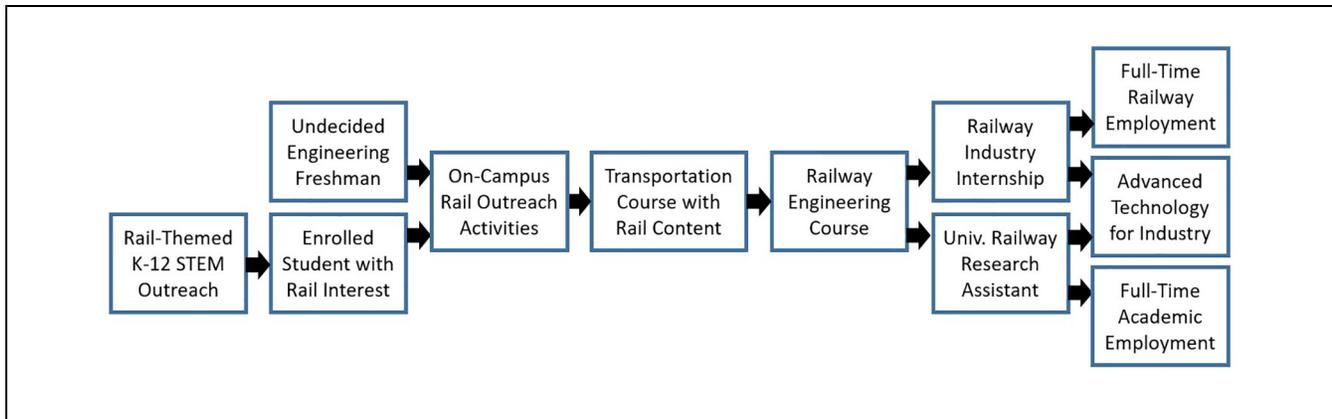


Figure 1. University pathway to the rail industry.

specialized” and tie their future career prospects to a narrow engineering field and the financial health of one particular industry. These students desire to keep their options open by focusing on general courses and choosing engineering majors that are more general in nature. They may dabble in railway topics but are reluctant to fully commit to railways.

- **Parental guidance.** Many students are heavily influenced by their parents when selecting a major, determining areas of specialization, and considering possible career opportunities after graduation. Only students with the strongest interest in rail are likely to avoid being steered in a different direction by parents that, like most members of the general public, may incorrectly perceive railways as “low-tech”, ancient, or a dying industry with poor long-term career prospects.
- **General misconceptions.** Misconceptions about the railroad industry can be formed by students because of a lack of exposure to rail transportation, or even negative experiences compared with other transportation modes. Many students enter college having never once travelled by train, and long-standing terminology such as “train engineer” may conflict or be confused with the modern legal definition of a “professional engineer”. As a result, students are unaware of the large job market and diverse career opportunities offered by the railroad industry.

It is clear that to provide the rail industry with the volume of rail-aware students necessary to fill entry-level positions for graduating engineers, and to supply rail-focused courses and degree programs with a sustainable supply of enrollees, students must become introduced to railway engineering concepts at earlier junctures on the university pathway (Figure 1). The rail industry relies heavily on faculty engaged in railway

education and research to play an integral role in meeting the demand for railway transportation professionals by guiding students through this pathway. Faculty outreach to incoming freshmen may be aided by on-campus student groups, such as AREMA student chapters, who act as ambassadors and promote student awareness of the railway field. Engaging industry professionals through the AREMA student mentoring program can also help guide students with a developing rail interest through this pathway and into industry careers. However, students are not likely to seek out railway mentors until the later stages of their academic career or possibly not until graduate school, limiting the effect of this program on overall enrollment in rail courses.

While outreach to incoming freshman engineering students is critical, to further increase the pool of potential students for rail-focused courses, degree programs, and eventual industry careers, industry efforts to recruit students and promote the railway engineering field must take place earlier, during the pre-college portion of the pathway to industry. This view is supported by studies of the types of pre-college and college experiences that differentiate students who successfully complete engineering degrees from those who enroll but ultimately switch to another academic program (22). Successful engineering students are most likely to be those with direct exposure to engineering concepts and activities at the pre-college level, and those engaging with technical societies and engineering activities as undergrads (Table 1). While AREMA Student Chapters fill the needs of successful students while enrolled and pursuing their undergraduate degrees, there is no coordinated industry effort at the pre-college level.

Rail-Focused STEM Outreach

To engage students at the pre-college level, railway-focused faculty and AREMA Student Chapters have

Table 1. Comparing Students Finishing Engineering Degrees with those Switching Majors (22)

Timeline	Students successfully completing engineering degree programs	Students switching from engineering to other degree programs
Pre-College	Interest in STEM subjects Interest in engineering stimulated by exposure to engineering-related STEM activities and engineering professionals Some knowledge of engineering concepts and the profession	Interest in STEM subjects Interest in engineering stimulated by school guidance counselor or other non-engineers No knowledge of engineering concepts and the profession
As an Undergraduate	Engagement with engineering technical societies and participation in engineering-related activities Formation of a social and professional network in engineering	No engagement with engineering-related activities Formation of a social and professional network outside of engineering

conducted outreach to students enrolled in kindergarten through grade twelve (K-12), typically through railway-themed STEM activities. Promoting the STEM fields to K-12 students has been demonstrated to increase the number of high school students enrolling as freshman in related engineering programs (23). In particular, students who had research experiences in high school, who undertook an apprenticeship, mentorship, or internship, and whose teachers connected the content across different STEM courses were more likely to complete a STEM major than their peers who did not report these experiences.

The shortage of interested students is not isolated to the railway industry but instead spans multiple engineering, science, and technical fields. There are also an increasing number of traditionally non-STEM positions that now require STEM competencies, such as analytics and coding. Many business, academic, and policy leaders assert that U.S. STEM education weaknesses have contributed to national science and engineering workforce shortages and that this labor supply problem has diminished U.S. global economic competitiveness and threatened national security (24). Over the past decade, to promote student interest in pursuing university degrees in STEM fields, it has become a national priority to train teachers in STEM education and equip youth with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information.

A stronger emphasis on teaching science and mathematics fundamentals at the K-12 level has been complemented by the recent rise of the “maker movement”, a grassroots effort to encourage youth to tinker, hack, design, and invent (25). While traditional approaches to mathematics and science often present concepts in abstract contexts with limited applications, STEM-rich “making” activities engage learners in hands-on activities centered on the use of scientific and technical tools, processes, and phenomena. Physical phenomena or concepts such as balance, forces and motion, light, electricity and magnetism, resonance, symmetry, and others (depending

on the activity design) are explored through the practice of exploration, questioning, iterative design and testing, and problem solving. Making is a virtuous cycle: not only do students learn the design process central to engineering and technology development, but the design process becomes a powerful vehicle for reinforcing fundamental STEM concepts (26).

As an engineered system involving the movement of large heavy objects across infrastructure maintained to tight tolerances, railroad transportation lends itself to demonstrations of basic physics, engineering, mathematical, and economic concepts through interactive hands-on activities. While demonstrating STEM concepts and incorporating the engineering design, testing, and problem solving ideals of the “maker movement”, these hands-on activities can also introduce students to specific railway applications, technologies, and career opportunities. Additionally, railway-themed activities provide creative and design-related outlets in numerous engineering disciplines including civil, mechanical, electrical, environmental, computer science, and fluid mechanics. In this manner, rail-themed K-12 STEM activities provide a compounding benefit; not only do they increase student awareness of the broader engineering and technical fields, they also make students aware of specific careers in railway engineering and transportation. In the long term, increasing both the number of students entering engineering degree programs, and the fraction of them that are aware of the railway engineering field, will serve to increase the number of students that engage with AREMA Student Chapters, enroll in rail-focused courses, and matriculate in specialized railway degree programs.

Examples of Rail-Focused K-12 STEM Activities

The following list presents a number of rail-focused K-12 STEM activities developed at various universities engaged in railway engineering education and research activities. The listed activities were gathered from the



Figure 2. Students constructing a model of the railway track structure.

first-hand experience of the authors, and presentations, panel discussions, and small group breakout sessions at recent gatherings of academicians involved in railway engineering education and research. Specifically, presentations and discussions of K-12 outreach took place at: the 2015 NURail Annual Meeting, 2016 Railway Academic Conference, 2017 American Public Transportation Association (APTA) Passenger Railway Engineering Education Symposium (p-REES), and 2018 REES. The list is not intended to be comprehensive but instead to demonstrate that the activities can be centered on different railway functions from engineering to operations, and may relate to any number of civil, mechanical, and electrical phenomena and their underlying fundamental STEM concepts in physics and mathematics.

- **Track Structure Construction.** Students use sand, aquarium gravel, balsa wood crossties, push-pin “spikes”, and 3-D printed (or G-scale model railroad) rails to build a foot-long representation of the railway track structure on a cookie sheet (Figure 2). The students observe how, without the aquarium gravel “ballast”, the skeleton track structure is flexible and unstable. Using a spring scale, older students can measure the change in lateral resistance offered by the track structure before and after adding the ballast.
- **Drinking Cup Wheel-Rail Dynamics.** After demonstrating that a cup on its side will roll in a circle because of different rolling radii, students use plastic drinking cups and tape to assemble simple models of tapered railway wheelsets. The students are encouraged to arrange the tapered cups in different combinations and orientations and then test them by rolling them down a tangent and curved



Figure 3. Measuring rolling resistance with a spring scale.

section of representative railway track. The students can observe how the proper tapered wheelset oscillates to negotiate the tangent and curved sections of track while other combinations are unstable, over-correct, and “derail”.

- **Railway and Roadway Rolling Resistance.** This activity compares the rolling resistance of two model railcars: one fitted with standard steel wheels rolling on model railway track, and one fitted with rubber radio-controlled automobile wheels and tires rolling on the table. Students use a spring scale to measure the rolling resistance of the two railcars, demonstrating how the steel wheel on steel rail contributes to the overall efficiency of railway transportation (Figure 3). Older students can change the weight carried by the railcars and the pulling speed to reveal different train resistance relationships.
- **Popcorn Railcar Size and Weight.** This activity demonstrates how the cubic capacity of railcars is optimally sized for the density of the freight commodity it is designed to carry. Containers filled with equivalent volumes of materials with different weights, such as plastic pellets, beans, and metal bee-bees, or unpopped and popped popcorn, are used to explain concepts of volume and density. Students then fill two open-top hopper car models of different cubic capacity with granular materials of various densities to determine if the material fills the volumetric capacity (“cubes out”) or, as measured by a kitchen scale, reaches the scaled-down railcar weight limit (“tares out”).
- **Intermodal Race Game.** The purpose of this activity is to demonstrate the efficiency of “intermodal” railway transportation of shipping containers relative to transporting them on individual trucks.

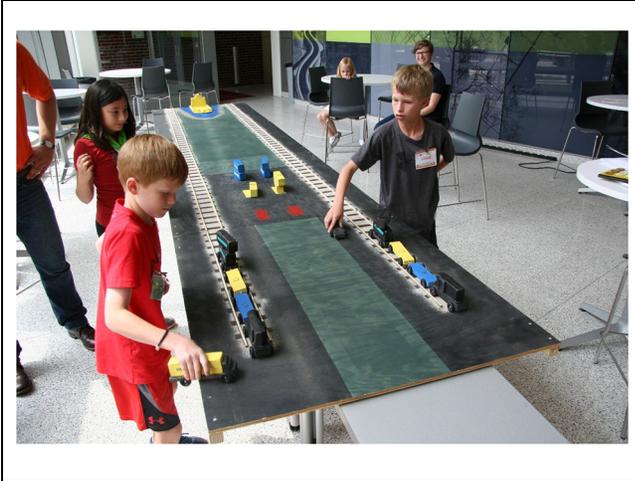


Figure 4. Racing to deliver containers by truck and rail in the intermodal game.

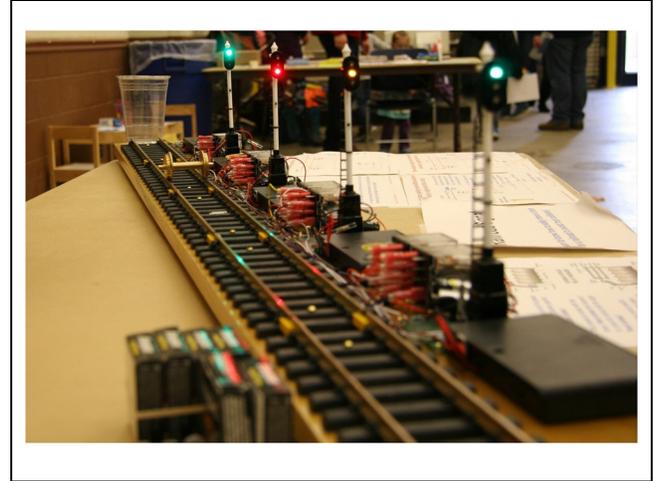


Figure 5. Functioning track circuit and automatic block signal display.

In the game, two students race to transport six wooden block “shipping containers” between a port and an inland terminal at either end of a long table (Figure 4). One student uses a single truck, while the competing student uses a train consisting of a locomotive and three double-stack railcars. The truck, locomotive, and railcars are all fabricated from Pinewood Derby car kits. Typically, in the initial stages of the race, the truck builds a lead making several round trips, while the train requires time to load all of the containers. However, by transporting all six containers in a single trip, the train quickly gains the advantage.

- **Wooden Railway Simulation.** In this activity, a small group of students work together to operate trains over a Brio-style wooden railway, earning revenue for every railcar they transport, but also incurring expenses for crews and fuel. As the students are prompted to increase their profits, they attempt to run more frequent and longer freight trains, requiring capital investments in additional passing sidings and siding extensions on the single-track route. Students learn basic concepts of transportation and railway economics, railway operations, train dispatching, and railway capacity planning.
- **BRIO Classification Yard.** Using Brio-style wooden railway track and railcars, students construct a representative classification yard according to a schematic layout of tracks and turnouts. The students are then guided through the process of switching an inbound train of wooden railcars labelled by block color or number into the different classification tracks. The basic activity can be extended by reducing the number of tracks and

explaining how multi-stage sorting can be used to form more blocks on fewer tracks.

- **Track Circuits and Automatic Block Signals.** Sections of large-scale model railway track, signals, and relays can be used to construct working models of the railway signal system. One example display uses approximately 5 feet of track affixed to a base (Figure 5). The rails are divided into five block sections separated by four block signals. Batteries and relays are used to create track circuits that are shunted by a turned brass wheelset. Students can roll a wheelset across the track sections, see and hear the relays engaging and the progression of stop, approach, and clear signal aspects behind the “train”.
- **Build a Simple DC Motor.** Using a D-size battery (or 9-volt with battery snap wire leads), two metal plates or paper clips, about three feet of 20 AWG magnetic wire, a large ceramic magnet, and a plastic or wood base, students build a basic DC motor. This teaches students about electro-magnetism and introduces them to the basics of DC motors used in many diesel-electric locomotives. This activity provides a good introduction to the topics of engines, generators, and motors that provide tractive power for a locomotive.
- **Locomotive Simulator.** Various commercial train simulators such as Run8, Trainz, and Microsoft Train Simulator provide uses with an interactive, in-cab locomotive engineer perspective of train operations. When combined with a large flat screen display and special commercial desktop controllers that simulate actual locomotive throttle, brake, bell, and horn controls, these software packages deliver an effective locomotive simulator

experience and help students to quickly recognize the differences in dynamics between different trains (heavy freight versus passenger). Experience suggests that simulations of commuter rail operations are most effective for student groups, as each student can quickly take a turn accelerating the train, holding it at speed, and braking to a (hopefully) precise stop at the next commuter platform.

- **Virtual Reality Headsets.** Technology companies are rapidly growing the field of 360-degree videos and virtual reality (VR) for use in educational environments. Google, Samsung, and Facebook (Oculus) have all released virtual reality headsets that can provide students with immersive learning experiences. Norfolk Southern and Operation Lifesaver have each created 360-degree railroad-oriented content and Penn State Altoona is now creating a small library of immersive educational videos that will include freight and passenger operations on U.S. railroads as well as European railways. Use of VR is recommended only for students above the age of twelve.
- **Operation Lifesaver and Railway Safety.** While stimulating student interest in railways, it is also important to reinforce fundamental railway safety rules at grade crossings and that trespassing on railway right-of-way is extremely dangerous and is a crime. Operation Lifesaver can provide railway safety educational materials and guest speakers to complement rail-focused K-12 STEM activities. Virtual Reality videos produced by Operation Lifesaver are also available for free on the internet.

Most of the activities listed above have several commonalities: 1) they encourage students to work together in small groups or as a team, 2) they encourage students to physically interact with scale models or representations of actual railway infrastructure and rolling stock, 3) students are encouraged to formulate hypotheses or make decisions on the best design alternative or approach to a particular element of railway technology, and 4) they involve observation and measurement of different trials, potentially analyzing and interpreting qualitative and quantitative data. This latter point provides an opportunity to adjust the scope of activities for different age groups; younger students can focus on working through the activity and making qualitative observations or simple measurements, while middle and high school students may make more detailed measurements, plot or analyze the data, and draw conclusions to reveal the form of underlying relationships. Several universities use these same activities as classroom demonstrations to accompany more detailed explanations of railway engineering

phenomena within their rail-focused courses for matriculated students or short courses for industry professionals.

Rail-Focused K-12 STEM Outreach Programs

Many of the rail-focused activities briefly described in the previous section were developed as part of larger K-12 STEM outreach programs. Examples include the Summer Youth Program in Rail and Intermodal Transportation at Michigan Technological University, Engineering Open House and summer STEM Camp railway day at the UIUC, Kids' College at Penn State Altoona, and support of the Boy Scouts of America (BSA) "Railroading" merit badge at various campuses.

Michigan Technological University, in collaboration with the University of Wisconsin-Superior, has been running a week-long Summer Youth Program (SYP) in Rail and Intermodal Transportation (27). The SYP had six participants during its inaugural run in 2010, but later expanded to attract up to 25 students from grades 9-11, nationwide. Much of the expansion occurred after NURail became involved with supporting the program in 2013. With NURail funding, Michigan Tech was able to match the 50% scholarship initially provided by industry gifts and a special focus was added to attract minorities to the program. The minority aspect has also been strengthened through a collaborative effort with Illinois and Hanson Professional Services since 2014. The program includes classroom lectures, industry visits, and hands-on activities. In addition to the classroom activities introduced in the previous section, the highlight of the program has consistently been the numerous field visits to various industry facilities, including Lake Superior and Ishpeming Railroad, Halvor Lines (trucking company), CN ore/taconite docks, BNSF rail yard, and North Shore Railroad Museum. While it is difficult to accurately quantify how many of the 125 students that have participated in the program since 2010 have continued to rail-related university studies or careers, at least eight of them have joined Michigan Tech for their university studies. Two students have also recently been identified who have since started their studies at the UIUC. These students tend to be a step ahead of other incoming freshmen in getting involved in on-campus rail activities, such as the AREMA student chapter, as they have already developed a connection with the rail transportation faculty during the summer program.

Each summer since 2015, the University of Illinois Rail Transportation and Engineering Center (RailTEC) has also hosted a "railway day" in cooperation with a local provider of STEM-focused summer camps (28, 29). During the day-long event, RailTEC graduate students, faculty, and alumni volunteer as guides for various rail-focused STEM activities as the campers rotate between

activities. The Illinois AREMA Student Chapter has also taken these activities on the road to stage similar events at elementary schools in the communities surrounding campus.

Rail-focused STEM exhibits and activities are also staged by the University of Illinois AREMA Student Chapter each year at Engineering Open House (EOH). A two-day student-led event encompassing the entire engineering campus, EOH encourages K-12 students and the public to visit engineering labs on campus and experience hands-on STEM activities. In addition to several of the activities listed earlier, the AREMA Student Chapter assembles a full-scale track panel inside the civil engineering building and uses it to explain various track components and track tool to the public. The Illinois student chapter has also partnered with CN, BNSF, Norfolk Southern, and Central Japan Railway to have professional railroaders attend EOH to display train control and dispatching systems, hi-rail maintenance trucks, models of magnetic levitation (maglev) trains, and information on recent engineering and capital expansion projects. Since 2014, RailTEC has partnered with Hanson Professional Service to bring 25 minority and disadvantaged students from Springfield, Illinois with strong academics and an expressed interest in STEM fields to tour EOH while accompanied by RailTEC graduate students. Several past attendees from Springfield have gone on to enroll in civil engineering degree programs and hold summer internships with Hanson (30).

In 2017, Penn State Altoona launched a one-week Railroad Engineering program for 11–14 year-old students as part of the annual Kids' College hosted throughout the summer in Altoona (31). Eight students participated in 2017 and there were nine participants in 2018. The goal is to continue this annual program and increase student participation each year. During this week-long half-day camp, RTE faculty worked with student assistants to offer an interactive program using several of the K-12 STEM activities listed in the above section. Starting in 2018, Penn State began to incorporate 360-degree virtual learning into the Kids' College program. Students used the Samsung Gear VR virtual reality headset platform with Galaxy Note 8 smartphone to take virtual tours of various railroad industry locations. In addition to the annual Kids' College, the RTE program has worked with other departments at Penn State Altoona to offer a railroad engineering module for a "women in engineering" STEM program for junior high students. The track structure construction activity was used for this program, reaching 40 female junior high students from several schools from the Altoona area.

A final nationwide opportunity to engage in rail-focused outreach to boys and girls is through the BSA

"Railroading" merit badge (32). The merit badge requirements encourage scouts to explore various facets of the railway industry. Local scout troops are often in need of volunteers with a railroading background to help guide scouts through the "Railroading" merit badge requirements. The AREMA Student Chapters at Michigan Tech, Illinois, and Penn State have each helped organize "Railroading" merit badge clinics where scouts can learn about railroads and complete the badge requirements in a single day under the guidance of rail-focused undergraduates, graduate students, and faculty instructors.

Efficacy of Rail-Focused K-12 STEM Outreach

Because of the small number of rail-focused K-12 programs described above and their relatively short history, it is difficult to assess the efficacy of rail-focused K-12 STEM outreach. With the possible exception of week-long summer camps, it is not possible to track the education and career paths of many program participants or those who spend a few minutes interacting at an open house. For recent programs aimed at younger students, it may be many years before the students involved in these programs make decisions on post-secondary education and career paths. Other than anecdotal evidence from a small number of observations, or the limited quantitative evidence of the Michigan Tech SYP discussed earlier, it can only be assumed that rail-focused STEM activities will be consistent with published literature describing the efficacy of STEM outreach in attracting students to a broader range of engineering fields and degree programs at the post-secondary level (22, 23). A future option is to survey matriculated railway engineering students to determine which types of activities they were involved in as K-12 students and what influence the various activities had on their decision to enroll in a rail-specific program and pursue a career in the rail industry.

Conclusion

In order for the railroad industry to compete with other engineering fields in recruiting top talent, outreach must begin at a young age. Lessons from active STEM programs can help inform industry and academia in best practices for fostering interest that will lead to future workforce development. Several universities and AREMA-affiliated companies have begun to adopt this long-term vision. The University of Illinois, Michigan Technical University, and Penn State Altoona, among others, have worked to advance K-12 outreach through various initiatives. However, additional collaboration among industry and academia is still needed to generate the level of exposure and interest in railroad engineering required to meet future workforce demands. Both public

and private investment will be required to advance this collaborative effort as K-12 outreach programs provide exposure to railroad engineering through creative, hands-on, and technology-related initiatives. Just as railroads conduct long-term and strategic planning for capital investment, similar planning and investment is needed for developing human capital that will grow to become the engineering professional workforce of the future.

Acknowledgment

This paper has been supported by the National University Rail (NURail) Center, a U.S. DOT-OST Tier 1 University Transportation Center.

Author Contributions

The authors confirm contribution to the paper as follows—study conception and design: CTD, PL, BWS; draft manuscript preparation: CTD, PL, BWS. All authors reviewed the results and approved the final version of the manuscript.

References

- Lautala, P. T., C. T. Dick, D. Rizos, and D. B. Clarke. Toward the Next Generation of Railroad Professionals – Collaboration by NURail and Rail Industry. *Proc., American Railway Engineering and Maintenance-of-Way Association Annual Conference*, Minneapolis, Minnesota, 2015.
- Lautala, P. T., and C. T. Dick. Railway Engineering Education Symposium: Evolving to Rebuild a Growing Rail Academic Community. *Transportation Research Record: Journal of the Transportation Research Board*, 2017. 2608: 96–104.
- Barkan, C. P. L. Building an Education Infrastructure for Railway Transportation Engineering: Renewed Partnerships on New Tracks, *TR News*, Vol. 257, 2008, pp. 18–23.
- Huffman, W.H. One Way in Which Committee 24 is Interesting Students in Railroading. *Proc., American Railway Engineering Association Annual Conference*, Chicago, IL, 1958.
- Everitt, W. L. What Price Glamour. *Proc., American Railway Engineering Association Annual Conference*, Chicago, IL, 1964.
- Lautala, P. T. From Classroom to Rail Industry – A Rail Engineer in the Making. *Proc., American Railway Engineering and Maintenance-of-Way Association Annual Conference*, Chicago, IL, 2007.
- Reis, V., and R. Macario. Competences Gap in European Railways Education. *Transportation Research Record: Journal of the Transportation Research Board*, 2012. 2275: 111–119.
- Patton, E. P., C. J. Langley, Jr., and M. S. Bronzini. Reviving Railroad Education in the United States: Programs for the 1980s and Beyond. *Transportation Research Record: Journal of the Transportation Research Board*, 1980. 748: 5–12.
- Railroad Facts 2015 Edition*. Association of American Railroads, Washington, D.C., 2015.
- Freight Railroad Capacity and Investment*. White Paper. Association of American Railroads, Washington, D.C., 2016.
- Cambridge Systematics. *National Rail Freight Infrastructure Capacity and Investment Study*. Prepared for the Association of American Railroads, Washington DC, 2007.
- Employment Data*. Surface Transportation Board, Washington, D.C., 2015. <https://www.stb.gov/econdata.nsf/>.
- Amtrak Annual Report: FY2014*. National Railroad Passenger Corporation, Washington, D.C., 2015.
- DiDomenico, G. C., and C. T. Dick. Analysis of Trends in Commuter Rail Energy Efficiency. *Proc., 2014 Joint Rail Conference*, Colorado Springs, 2014.
- 2015 Public Transportation Fact Book. Appendix A: Historical Tables*. American Public Transportation Association, Washington, D.C., 2015. <https://www.apta.com/resources/statistics/Documents/FactBook/2015-APTA-Fact-Book-Appendix-A.pdf>.
- Hernandez, P. D., and P. J. Haas. Estimating Workforce Needs for High-Speed Rail in California and the United States. *Transportation Research Record: Journal of the Transportation Research Board*, 2013. 2328: 25–31.
- Lautala, P. T. What the Railroad Industry Needs and Expects from Higher Education: Meeting the Needs. *Transportation Research Record: Journal of the Transportation Research Board*, 2013. 2329: 32–39.
- ICF International. *Strategies to Attract and Retain a Capable Transportation Workforce*. National Cooperative Highway Research Program, NCHRP Report 685. Transportation Research Board, Washington, D.C., 2011.
- Qinetiq North America. *A Guide to Building and Retaining Workforce Capacity for the Railroad Industry*. National Cooperative Rail Research Program, NCRRP Report 2. Transportation Research Board, Washington, D.C., 2015.
- Lautala, P. T., and W. J. Sproule. Rebuilding Railroad Engineering Education in the United States with Industry-University Partnerships. *Transportation Research Record: Journal of the Transportation Research Board*, 2009. 2109: 37–44.
- Lautala, P. T., C. T. Dick, J. L. McKinney, and D. B. Clarke. Railway Engineering Education Symposium (REES) - Universities and Industry Collaborate to Develop Railway Education. *Proc., 2013 ASME Joint Rail Conference*, Knoxville, TX, 2013.
- Pierrakos, O., T. K. Beam, J. Constantz, A. Johri, and R. Anderson. On the Development of a Professional Identity: Engineering Persists vs Engineering Switchers. *Proc., 39th ASEE/IEEE Frontiers in Education Conference*, San Antonio, TX, 2009.
- National Research Council. *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. Committee on Highly Successful Science Programs for K-12 Science Education. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education, Washington, D.C., 2011.
- Gonzalez, H. B., and J. J. Kuenzi. *Science, Technology, Engineering and Mathematics (STEM) Education: A Primer*. CRS Report for Congress, Congressional Research Service, Washington, DC, 2012.

25. Bevan, B., J. P. Gutwill, M. Petrich, and K. Wilkinson. Learning through STEM-Rich Tinkering: Findings from a Jointly Negotiated Research Project Taken Up in Practice. *Science Education*, Vol. 20, No. 10, 2014, pp. 1–23.
 26. Honey, M., and D. Kanter. *Design, Make, Play: Growing the Next Generation of STEM Innovators*. Routledge, New York, 2013.
 27. Michigan Technological University. *Rail & Intermodal Transportation Summer Youth Program*. <http://www.rail.mtu.edu/event/rail-intermodal-transportation-summer-youth-program-2018>. Accessed November 1, 2018.
 28. Innes, E. *STEAM Studio's STEAMcation Students Visit RailTEC...Learn All About Trains*. University of Illinois at Urbana-Champaign I-STEM Education Initiative. <https://www.istem.illinois.edu/news/steamcation@railtec.html>. Accessed November 1, 2018.
 29. Innes, E. *Illinois' Chris Barkan and RailTEC Convey the Message: "Trains—They Run on 'STEAM' and They're Terrific!"*. University of Illinois at Urbana-Champaign I-STEM Education Initiative. <https://www.istem.illinois.edu/news/steamcation@railtec.html>. Accessed November 1, 2018.
 30. Codemo, R. *Homegrown Engineers*. Springfield, IL, 2015.
 31. Penn State Altoona. *2018 Kid's College Brochure*. <https://altoona.psu.edu/content/kids-college-2018-brochure-adobe-pdf>. Accessed October 15, 2018.
 32. Boy Scouts of America. *Merit Badge Series: Railroading*. https://filestore.scouting.org/filestore/merit_badge_reqandres/railroading.pdf. Accessed November 1, 2018.
- The Standing Committee on Transportation Education and Training (ABG20) peer-reviewed this paper (19-02628).*