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A Collaborative K-12 STEM Education Framework Using Traffic Flow as a Real-world Challenge Problem

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Prof. Biswas conducts research in Intelligent Systems with primary interests in hybrid modeling, simulation, and analysis of complex embedded systems, and their applications to diagnosis, prognosis, and fault-adaptive control. As part of this work, he has worked on fault diagnosis and fault-adaptive control of secondary sodium cooling systems for nuclear reactors, automobile engine coolant systems, fuel transfer systems for aircraft, Advanced Life Support systems and power distribution systems for NASA. He has also initiated new projects in health management of complex systems, which includes online algorithms for distributed monitoring, diagnosis, and prognosis. More recently, he is working on data mining for diagnosis, and developing methods that combine model-based and data-driven approaches for diagnostic and prognostic reasoning. This work, in conjunction with Honeywell Technical Center and NASA Ames, includes developing sophisticated data mining algorithms for extracting causal relations amongst variables and parameters in a system. For this work, he recently received the NASA 2011 Aeronautics Research Mission Directorate Technology and Innovation Group Award for Vehicle Level Reasoning System and Data Mining methods to improve aircraft diagnostic and prognostic systems.

In other research projects, he is involved in developing simulation-based environments for learning and instruction. The most notable project in this area is the Teachable Agents project, where students learn science by building causal models of natural processes. More recently, he has exploited the synergy between computational thinking ideas and STEM learning to develop systems that help students learn science and math concepts by building simulation models. He has also developed innovative educational data mining techniques for studying students' learning behaviors and linking them to metacognitive strategies. His research has been supported by funding from NASA, NSF, DARPA, and the US Department of Education. His industrial collaborators include Airbus, Honeywell Technical Center, and Boeing Research and Development. He has published extensively, and has over 300 refereed publications.

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A Collaborative K-12 STEM Education Framework Using Traffic Flow as a Real-world Challenge Problem

Abstract

Effective science, technology, engineering and mathematics (STEM) education can be better supported by teaching tools that promote critical thinking and modalities that situate learning in the context of real-world problems. This is emphasized in the next generation science standards (NGSS) for high school engineering, where students are expected to engage with the global issues at the interface of science, technology, society and environment [4]. Study of traffic flow patterns is one such real-world problem domain that can stimulate student interest in STEM domains. To scaffold students' modeling and analysis of traffic flow, we have developed a suite of intuitive, easy-to-use and grade-appropriate tools that link problem solving to fundamental STEM concepts, and provide input and output interfaces to more complex and scaled up traffic simulation systems. We have developed a first prototype of the system, called C^3STEM (Challenge-based Community-centered Collaborative STEM learning environment) for ubiquitous learning in the classroom and outside.

We evaluated an initial prototype of our system by introducing it to two groups of students. The first group of seven 10th and 11th grade students from a local Nashville High School, pursuing an Engineering track in their high school curriculum, worked on problems that combined math and science concepts. Using various components of our framework, the students first enhanced their knowledge of physics (Newton's laws) and mathematics (elementary calculus) and applied them to solve engineering problems related to reducing traffic congestion and maximizing vehicular throughput by traffic signal programming while experimenting with ranges of transportation parameters. The second group, nine middle school students attending a science summer camp in Chattanooga, TN, focused on the kinematics concepts associated with modeling traffic flow. Feedback from the students is helping us enhance the tool capabilities for use in a STEM curriculum at two high schools in summer and fall, 2014.

Introduction

STEM occupations are projected to grow by 17.0% from 2008 to 2018 in the United States [6]. However, there is a growing shortage of students who pursue STEM careers, primarily because they seem to develop a lack of interest in STEM topics that may be traced back to unavailability of teaching tools and resources that develop STEM concepts in realistic and motivating contexts along with relevant challenge problems. Often students are not made aware of the link between engineering disciplines and their focus on solving important societal problems. This has been highlighted in various studies of service-learning curriculum [8]. Thus, there is a need for effective teaching modalities with supporting resources, employing real-world examples and challenge problems to motivate students, and promoting interactive and collaborative learning so that students can adopt inquiry-based learning methods and collectively solve complex problems.

Simulation environments have been employed for modeling, analyzing, and understanding real world physical processes as well as operations of engineered artifacts to help reinforce STEM concepts. However, existing tools are too complex for high school students, and incur steep learning curves, though there are a few related examples that bridge this gap. Whitman and Witherspoon [9] investigated the use of the LEGO toolkit to engage high school students in STEM education by modeling and studying manufacturing processes. However, they did not show a direct co-relation between the knowledge gained and the curriculum taught in the high school syllabus. Mataric et al. [7] described the use of robotics for experiential and hands-on education by providing a platform that students and teachers can use to study the hardware and software designs for constructing a robot. In their paper, they addressed the cost concerns of using and maintaining such platforms in school environments. Kim et al. [5] designed a web-based game activity to help middle school students learn mathematical and scientific concepts by studying acoustics and music problems. In pilot studies, they demonstrated that the focus on real-world problems increases student interest.

In our work, we build on prior work and leverage web-based technologies and advances in ubiquitous handheld devices, to develop a community-situated, challenge-based, collaborative STEM learning environment (C^3STEM). As a real-world anchor, we focus on transportation. We have adopted a two-step approach to promote learning of fundamental concepts while also scaffolding the solutions for complex real-world problems. Students first learn the fundamental STEM concepts by building agent-based simulation models of vehicle operations using our tool called Computational Thinking in Simulation and Model-Building (CTSiM) [1]. Students model vehicles slowing down and speeding up at STOP signs, and vehicle flow in traffic on city streets that may include traffic lights and turns by applying Newton’s laws and calculus concepts. Once they demonstrate proficiency in building and simulating these models, they move on to our second tool called the Cloud-based, Collaborative, Scaled-up Modeling Environment (C^2SuMo) to model and work on larger, complex problems that are more realistic, real-world scenarios. They include flow of traffic on multiple city streets, sets of traffic lights, and the occurrence of different traffic patterns, such as congestion. Students run a number of experiments to become familiar with the effects of changing traffic parameters (such as density of vehicles, timing and sequencing of stop lights) on traffic patterns (e.g., a smooth flow of traffic versus congestion) using interfaces that are intuitive and facilitate collection of experimental data, performing statistical analyses, and plotting results.

For this paper, we focus on the second component of C^3STEM, i.e., C^2SuMo. The tool suite is still evolving and substantially more user studies are required to evaluate its capabilities. Therefore, in this paper we describe two preliminary user studies we conducted with high school and middle school students to determine the effectiveness of our framework, and determine the next steps in evolving the system.

Cloud-based, Collaborative, Scaled-up Modeling Environment (C^2SuMo) Framework

Approach

To make learning engaging and ubiquitous, we are developing a cyber-enabled educational infrastructure, which seamlessly integrates individualized and collaborative learning. We chose transportation as the problem domain as traffic overtly affects nearly everyone in the community, and it provides a set of rich scenarios for applying STEM concepts. By focusing on real-world scenarios, and familiar problems in traffic flow, such as congestion, students can then learn approaches to engineering problem solving. In addition, traffic flow is a well-studied problem, and plenty of data [10] and simulation environments [2] are readily available for providing the basis for constructing pedagogical tools. The C^{2}SuMo framework allows for modeling and simulation of scaled up traffic scenarios, which can then be used for analyzing traffic flows in segments of urban regions that may combine city streets and highways. In collaborative learning scenarios, the study of traffic patterns over a large region may be subdivided into parts, local solutions can be generated for each part, and then combined in a consistent manner to derive a global solution.

Traffic Modeling and Simulation

To ensure that the interface to the learning environment is intuitive and easy-to-use, we chose Google Maps [3] as the user interface since it is widely used and most likely familiar to students. Google Maps provides content-rich, multi-layered, and up-to-date aerial imagery map services. Unfortunately, Google Maps on its own does not possess any executable semantics and hence cannot display dynamic behavior. To overcome these limitations yet preserve the intuitive nature of Google Maps, we used its underlying application programming interface (API) to introduce new artifacts that provide students with an opportunity to model traffic flow scenarios and manipulate a range of parameters like vehicles, turn probabilities, and traffic light logic, each of which reifies one or more STEM concepts. Figure 1 illustrates the C^{2}SuMo web user interface presented to the high school and middle school students. The left side panel shows the artifacts whose parameters can be modified. The right side panel's zoomed-in area displays one of the traffic intersection artifacts that students can control by setting the timing intervals for the cross street traffic lights.

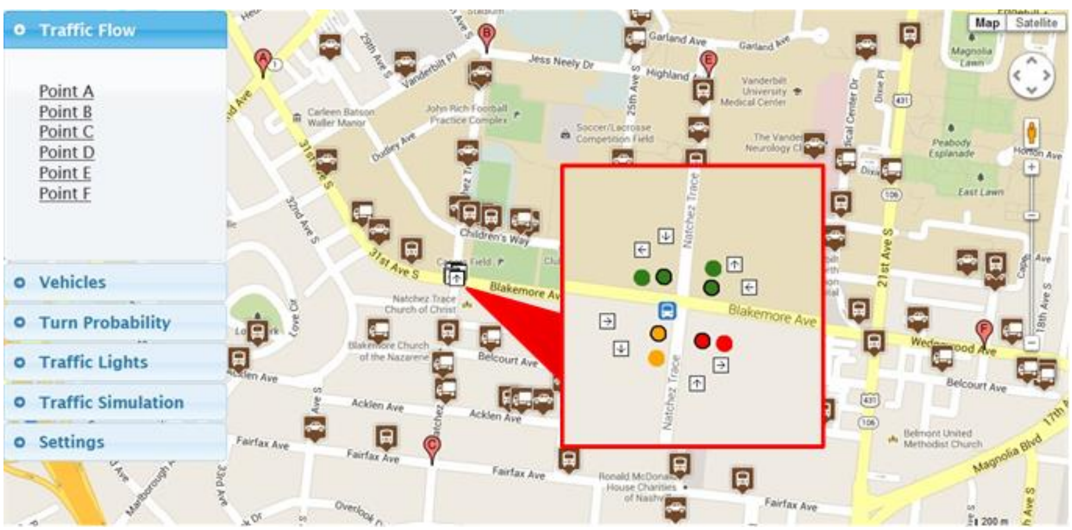

Fig.1. C^{2}SuMo Interface

The actual execution is performed on a real transportation simulator called Simulation of Urban Mobility (SUMO) [2] that executes in the background – in our case it is actually hosted in the cloud. Students do not directly access this simulation program. Transformations are used to convert the artifacts and their parameters specified in the Google Maps interface to the format appropriate to the backend simulator. A middleware solution for the cloud-based simulator has been developed which ensures that as more students join the simulation framework, it scales to keep all the simulation experiments running independently. When the students work together in the collaboration mode, the framework collates the two simulation instances so that students can combine simulations from adjoining regions, and conduct experiments to study the impact of one set of parameters on the other set.

Preliminary User Studies and Evaluation

Test Setup

We conducted two preliminary user studies on different groups of students to evaluate students' ability to use our framework to perform their modeling, simulation, and problem solving tasks. The first study involved a group of seven high school students from 10^{th} and 11^{th} grades of a Science and Math Magnet school in Nashville, TN. These students were on a summer internship program at our institute. The seven students were divided into two groups: Group A with three students and Group B with four students. Both groups appointed leaders who had the administrative role implying they were in charge of running the simulation. The administrative leader from group B was appointed the super administrator, i.e., when the two groups worked together, this student was in charge of controlling the joint experiments executed in the simulation environment. All students worked individually in Step I of the C^3STEM project where they used the CTSiM agent-based simulator for learning fundamental physics and calculus concepts. In Step II, the students initially worked individually with the C^2SuMo to model traffic flows through an intersection, and then collaborated with other members of their group to run additional experiments for that intersection. Finally, the two groups worked together to coordinate traffic flow through adjacent intersections. This required them to combine the simulation models for the two groups. The students spent about 4 hours a day and a total of 5 days on the project. At the end, they generated a report and presented their findings at the end of their internship studies.

The second study was performed with a group of nine middle school students attending a science summer camp in Chattanooga, TN. These students did not have a sufficient STEM background, and, therefore, were not as motivated towards STEM education as the group of high school students in the previous study. To match the level of middle school students, some of the parameters such as acceleration and deceleration were provided to them since they do learn the quantitative forms of Newton's laws in middle school. The middle school students were divided into two groups of four and five students, respectively, and the roles were assigned just like the previous study. We used a standard assessment method, i.e., pre and post tests to evaluate their learning.

Challenge Problems

The students challenge problem was to model city traffic and study traffic flows. Each group was responsible for a 4-way bidirectional traffic intersection. Vehicles of different types start from pre-defined locations and pass through the intersections. The students controlled vehicle types, vehicle count, their generation probabilities, turning probabilities at the intersection and the traffic signal logic. This exercise helped students learn a real traffic scenario by studying the impact of different parameters on the flow rates, waiting times, and other indicators of traffic congestion. The goal for the students was to \ work collaboratively to solve the real life problem of reducing traffic congestion in city streets. Students worked on four problems described below:

Problem 1: Modify vehicle count and parameters for three types of vehicles -- cars, buses and trucks, and vehicle turning ratios at the intersection, and study the impact on the overall simulation.
The purpose of the problem was to familiarize the students with the environment and let them develop an understanding of specific traffic scenarios. The students used physics and mathematics concepts to build their models, and identify different parameters in these models that influence traffic flow in a significant manner.

Problem 2: Keep all the existing parameters constant and attempt the following:
1 - Assign vehicle the probability of vehicle numbers to be equally distributed for the three vehicle types, and run the simulations to compute the average queue lengths and average waiting times for traffic in the different directions at the intersection under consideration.
2 - Increase the probability of trucks, and re-run the simulations to observe the changes in average queue lengths and waiting times at the intersection.
3 - Further increase the probability of trucks, and re-run the simulations to recompute all of the statistical parameters.
Compare the values found in 1, 2, and 3, and explain the effects of increasing the number of trucks on the average queue length and waiting time at the intersection. The purpose of this problem was to make the students learn the impact of larger and slower vehicles on the traffic by studying some of the indicators of traffic congestion.

Problem 3: Keep all the existing parameters same but tweak the traffic light logic with the goal of reducing the average queue lengths and average wait times at the intersection for different traffic light timing sequences. Compare and discuss the results. In this problem, the students attempted to solve the city congestion problem by controlling the traffic signals.

Problem 4: Keep all the parameters constant and observe the average queue length and flow rate of the lane from which traffic is emerging and entering the other intersection. Change the traffic light logic to maximize flow rate and minimize average queue length for the same. This problem was designed to evaluate the collaboration mode where each group could affect other group's traffic with the traffic light logic at their own intersection, and thus help them to learn to work on traffic problems collaboratively.

Results and Observations

The students were able to come up with satisfactory solutions for the problems, except for the last one, which we could attribute to the lack of fixed routes in the simulation. We have worked on the problem and rectified it in a later version of the framework.

For Problem 1, in addition to learning the behavior of the system, the students learned the physics and mathematics concepts for determining appropriate model parameters. One of the indicators of their learning was their observation that the actual values need not exactly match the probability, i.e., it is different from ratios. For Problem 2, the students concluded that increased vehicle size and reduced speed and acceleration adversely impacted traffic flow. Also, they were able to reason the unexpected results of reduced waiting queue with uniform large size vehicles. These results illustrate that stduents learned basic traffic engineering and computational thinking concepts. For Problem 3, the students came up with solutions for reducing traffic congestion by programming traffic light logic. One solution kept shorter cycles for the red light, gave less time for left turns and put experimentally determined total cycle duration, whereas another solution reduced longer green lights in order to reduce cycle time and red lights.

The student responses for middle school students were similar but not as elaborate as the high school students. Their overall learning was determined from pre and post test gains. The test contained two sections having questions related to modeling and to assess learning related to basic physics and mathematics. One section was from the traffic domain and other from the ecological domain. Six out of nine students showed an average net gain of 10.3 percent in their scores. The students who did not do well on the post-test seemed to have partial responses to the post-test questions, and we surmise possibly because they did not want to answer the questions they had on the pre-test again. Since the pre-test scores were not given to them before they took the post-test, they had no idea how they had performed on the earlier test.

In both the studies, students provided valuable feedback about the framework. One of the most positive one was about the use of Google Maps as the modeling and simulation interface. They thoroughly enjoyed working with it. They also found the tool very intuitive and could work on the problem sets with minimal guidance. There were several comments on improving the C^2SuMo interface, which we are addressing in the next version of our framework. Other than that, there were some notable suggestions about the problem sets. They preferred the problems to be more objective than the open-ended ones. As for modeling traffic signals, the consensus was to have a phase-based logic where all the signal data could be entered using a single interface instead of inputting data separately. This would help them to better visualize the traffic light logic. We addressed this requirement in our prototype.

Conclusion

In this paper, we presented our cloud-based, interactive, collaborative, scaled-up, and intuitive modeling environment for STEM education called C^2SuMo that is the second components of the C^3STEM framework that aims to stimulate high school and middle school students' interest in STEM concepts by enabling them to solve real-world problems from the transportation domain. Both individual and collaborative mode user studies were conducted with seven high school and nine middle school students. The positive response from our user studies for using Google Maps and real-world traffic problems as the motivational tools to learn STEM concepts, strengthen computational thinking, and reinforce previously learned STEM concepts has given us confidence to take our framework to the next level. We plan to develop an academic curricular unit to be used at two local schools. A long-term goal calls for supporting domains beyond just transportation for STEM education, and we believe pluggable component architecture enables our modeling framework to interact with other domains as well. In the future, a compatible component from other domains could be plugged into our modeling framework to teach students new or existing STEM concepts in a new domain.

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References

1. Dukeman, A., Caglar, F., Shekhar, S., Kinnebrew, J., Biswas, G., Fisher, D., & Gokhale, A. (2013). Teaching Computational Thinking Skills in C3STEM with Traffic Simulation. *1st IEEE International Conference on Human Factors in Computing & Informatics.* Maribor, Slovenia.

2. Behrisch, M., Bieker, L., Erdmann, J., & Krajzewicz, D. (2011). Sumo-simulation of urban mobility-an overview. *SIMUL 2011, The Third International Conference on Advances in System Simulation*, (pp. 55-60).

3. *Google Map*. (n.d.). Retrieved December 2013, from Google Map: https://maps.google.com/

4. *High School Engineering Design*. (n.d.). Retrieved October 2013, from NGSS: http://www.nextgenscience.org/sites/ngss/files/HS%20ETS%20Storyline%20-%20DCI%20and%20Topic-6.13.13.pdf

5. Kim, Y. E., Doll, T. M., & Migneco, R. (2009). Collaborative online activities for acoustics education and psychoacoustic data collection. *IEEE Transactions on Learning Technologies, 2*(3), 168-173.

6. Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011, July). *Stem: Good jobs now and for the future. esa issue brief# 03-11*. Retrieved December 2013, from Economics and Statistics Administration: http://www.esa.doc.gov/Reports/stem-good-jobs-now-and-future

7. Mataric, M. J., Koenig, N. P., & Feil-Seifer, D. (2007). Materials for Enabling Hands-On Robotics and STEM Education. *AAAI Spring Symposium: Semantic Scientific Knowledge Integration*, (pp. 99-102).

8. Eyler, J., & Dwight, G. E. (1999). Where's the Learning in Service-Learning? Jossey-Bass Higher and Adult Education Series. Jossey-Bass, Inc.

9. Whitman, L. E., & Witherspoon, T. L. (2003). Using LEGOs to interest high school students and improve K12 stem education. *change 87*, 76.

10. U.S. Department of Transportation's Research and Innovative Technology Administration (RITA), http://www.rita.dot.gov/about_rita/, 2014