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Increasing Student Motivation and Performance through Inquiry Based Learning with STELLA Systems Thinking and Simulation Software

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Synopsis:

The effect of Collaborative Project Based Learning (CPBL) on student performance and motivation in undergraduate mathematical modeling classes is investigated. The inquiry based collaborative learning strategies that incorporate The American Museum of Natural History as a Learning Laboratory and the STELLA Systems Thinking software are introduced.

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Abstract

The effect of Collaborative Project Based Learning (CPBL) on student performance and motivation in undergraduate mathematical modeling classes is investigated. The Inquiry based collaborative learning strategies that incorporate The American Museum of Natural History as a Learning Laboratory and the STELLA Systems Thinking software are introduced. Student performance scores collected from two sections of mathematical modeling class with CPBL component (treatment group) and two sections of mathematical modeling class without CPBL component (control group) demonstrate that bringing real-life context to the undergraduate mathematics classroom through project based collaborative learning improves student motivation and performance, promotes higher order mathematical thinking, and helps student transfer their mathematical knowledge to situations outside the classroom

I. Introduction

According to Thiel at al. (2008), student success in college mathematics depends on their mathematical skills, experiences (positive or negative) in previous math courses, and the level of motivation they bring in class. Students with positive attitudes are more likely to master course concepts and develop confidence in their mathematical abilities (Curtis, 2006). Learning mathematics is based on progressive reasoning. Students who lack foundational math skills struggle with advanced mathematical concepts and consequently form negative attitudes. Margolin, L., Sampoli-Benitez, B, and Tarasenko, A, (2012) investigated students' attitudes in two New York City Private High Schools with traditional mathematics curriculum and discovered statistically significant gender gaps in attitudes measured on the motivation, enjoyment, usefulness and self-confidence subscales. An overwhelming majority of female students underestimated the value and usefulness of acquiring scientific and mathematical skills, did not enjoy either working with numbers or solving science and math problems, and did not express any intellectual curiosity towards the subject matter.

Number of studies demonstrated that incorporating Collaborative Project Based Learning (CPBL) enhances student mathematical abilities and improves student attitudes towards the subject matter. Boaler (2002) conducted comparative study in two British secondary schools and found that students in the CPBL classroom outperformed students in traditional classroom not only in basic mathematical skills but also in higher level mathematical thinking. ChanLin (2008), and Karaman & Celik (2008) discovered that college mathematics students in CPBL achieve better academic performance compared with students in traditional teacher centered classroom. Kuo-Hung Tseng et al. (2011) investigated student attitudes towards science, technology, engineering (STEM) using surveys and semi structured interviews in a CPBL engineering class and discovered significant improvement in student attitudes after incorporating the CPBL.

One of the important goals of undergraduate mathematics education is to increase understanding and appreciation of mathematics as a mode of through and expression among Liberal Arts students. Research shows that Liberal Arts students have high math anxiety, low math self-efficacy and no motivation to take required math courses. Butler, M. & Butler, F. (2007) discovered that more than 60% of Liberal Arts students avoid taking mathematics and find it to be the most dreaded subject. Schwartz, R. H. (1992) suggested revitalizing Liberal Arts

Mathematics by incorporating CPBL. Latterel (2011) supported using mathematical inquiry in Liberal Arts mathematics instruction to increases student confidence and enjoyment. Inquiry based learning is very well suited for the CPBL. Mathematical inquiry requires students to pose questions, construct arguments, evaluate arguments, discover patterns, make conjectures and reach conclusions. Inquiry based learning encompasses situated learning Theory (Zastavker et al. 2006), constructivism (Hmelo-Silver, 2004), and cognitive psychology.

This article suggests revitalizing Liberal Arts mathematics by creating an environment that promotes high-impact learning opportunities through students' active engagement in mathematical and scientific inquiry. Section 2 explains importance of integrating inquiry based CPBL in Liberal Arts mathematics. Section 3 introduces strategies of incorporating Systems Thinking and Structural Thinking and Experiential Learning Laboratory (STELLA) as an inquiry based method of learning in Liberal Arts mathematical modeling classes. Section 4 discusses how to transform traditional classroom into authentic learning environment by integrating the resources of the American Museum of Natural History in the CPBL. Section 5 discusses effects of the CPBL with STELLA Systems Thinking and Simulations software on student performance and motivation in Liberal Arts mathematical modeling classes.

2. Inquiry Based Collaborative Learning in Liberal Arts Mathematics

Dweck (2006) found that the mindsets that students have about their academic ability influence their success in school. Students who believe that intelligence can be improved through effort and instruction (growth mindset) show higher achievement scores and greater course completion rates (Yeager and Dweck, 2012). Math is not inherently difficult but requires more work, more dedication, and more tenacity than some other Liberal Arts courses. Many Liberal Arts students have fixed mindsets, low self confidence in their mathematical abilities, and suffer from a math phobia. Teaching mathematics to Liberal Arts Students is different from teaching any other subjects because mathematics is the most misunderstood subject among students. Many students do not think of mathematics when they think of a Liberal Arts education despite the fact that for more than two thousand years mathematics has been a part of the human intellectual experience. Another misconception about mathematics among students is the notion that mathematics is all about memorizing boring collection of definitions, theorems, formulas, and rules. Many students are able to recall formulas and definitions of different concepts for a test but it does not necessarily mean that they understand the meaning behind each concept. Students do need to learn formulas and rules for problem solving. These mathematical skills are necessary and useful, but by themselves, without applications, they are useless. By making connections between mathematics and other disciplines such as arts, sciences, business, and economics, the real value of mathematics as language is better appreciated and students' ability to analyze and evaluate complex problems from interdisciplinary perspectives is greatly facilitated.

Effective teaching strategies should consider the hierarchy of learning, from simple to complex, and the ways students perceive and process the information. Levels of learning are generally based on cultivating inquiry through a question and answer approach, and consist of the following steps: awareness, understanding, application, generalization, and experimentation. It is important to increase the depth and rigor of instruction by moving from lower to higher levels of learning. However, not all learning situations require instruction and testing at all levels. Lower level math courses address awareness, understanding, and application levels while advanced interdisciplinary mathematics courses emphasize analysis, evaluation, generalization and experimentation levels.

Richmond (1993) hypothesized that incorporating systems thinking in classroom instruction promotes higher level thinking skills such as analysis and evaluation. Systems thinking engage learners in perspective- taking and foster interdisciplinary understanding of the complex system dynamics (Mathews, 2008). According to Sweeney (2014), thinking about systems helps students uncover patterns, interrelationships, and dynamics of complex systems involving people, places, events, and nature.

3. Integrating Systems Thinking in Liberal Arts Mathematical Modeling Classes

Mathematical modeling classes explore open-ended applications of mathematics, the processes and art of model building, and focus on investigatory teaching of the mathematics underlying dynamic modeling of biological, environmental, economical, sociological, and physical systems. In CPBL class sstudents approach the solutions to complex problems by asking questions, debating the ideas with each other, finding and analyzing information, and deriving conclusions.

The system thinking approach allows students to map interrelationships between different components of the system, simulate a system over time, and understand how change in one part of the system affects other part of the system. Students use STELLA systems thinking modeling and simulation software to build mathematical models representing a particular phenomenon, test constructed models using interactive simulations, and analyze data obtained from the model in light of the real-world setting. Students work in teams to explore a system of their choice from the list of the systems provided in the course syllabus. Students majoring in biomedical sciences are tending to choose either pharmacokinetics or epidemics models. Biology majors often explore dynamics of predation. Business and communication majors prefer working with urban dynamics, supply and demand, and investing and spending models. Students are required to formulate the problem, list the variables contributing to the problem, make assumptions, determine growth/decay patterns, develop a dynamic hypothesis, use STELLA diagram to visually represent components of the problem under study, explain what concepts are represented by stocks and what concepts are represented by flows, describe system behavior by using built-in functions, express the structure of the model as a simple stock/flow diagram and feedback loop, create graphical representation of the relationship between variables, make conclusions, explain limitations of the model and make reasonable decisions to improve the results of the model.

Fig. 1 represents a simple stock and flow diagram for a drug administration and elimination scenario. A patient is given intravenous shots of a certain amount drug in an equally spaced time intervals (Fisher, 2006). Students use one stock to describe the drug concentration in the body over time, one inflow with built-in PULSE command to describe drug infusion, and one exponential outflow including a converter for the elimination rate. Two additional converters are introduced to indicate minimum and maximum allowable therapeutic levels. The model is simulated for the 24 hours to explore dose-response regimen.

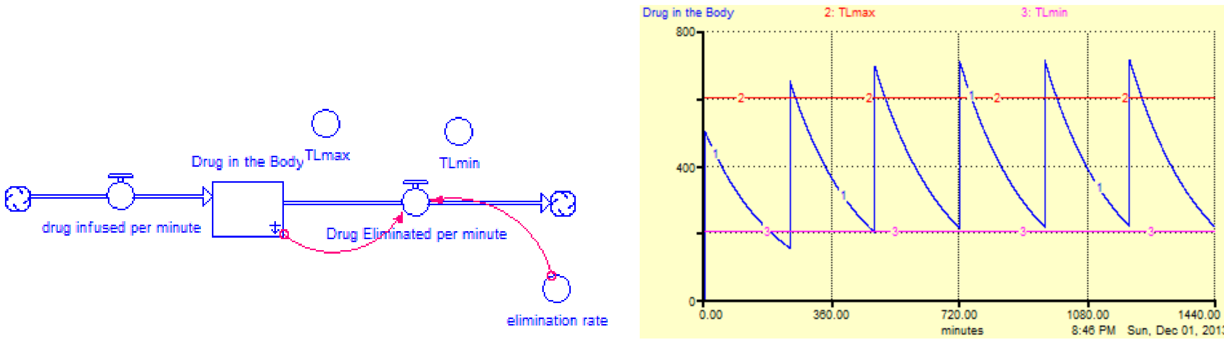


Fig. 1 STELLA Model for Drug Infusion and Elimination

STELLA graphics provide excellent visualization of the relationship between variables (Fig.1). The goal of the model is to determine optimal dosage and optimal time intervals for drug administration in order to maintain the drug level in a given therapeutic range. Students are asked to form their hypothesis regarding optimal dosing regimen and simulate the model to test the hypothesis. The goal is to get the model to achieve a desired drug level in a given time interval. Students are asked to interpret graphical output, explore dose-response relationships for different drugs and make appropriate modifications to the model to maintain effective dosing regimen for different situations such as kidney failure (abrupt reduction of drug elimination rate) or IV drug administration with a constant inflow of certain amount of drug in time.

Modeling spread of epidemics is another popular choice among science majors. STELLA built-in functions enable students to explore different aspects of the propagation of infectious diseases without applying differential equations. Students are required to brainstorm the factors effecting spread of epidemics, make reasonable assumptions, explore the time evolution of different (airborne and non-airborne) infections, develop and test dynamic hypothesis by simulating the model over time. Students start with a simple model where a small number of infected individuals are introduced into a large population. Simple epidemics model assumes that infected people are not dying and develop permanent immunity after recovery to maintain a constant total population.

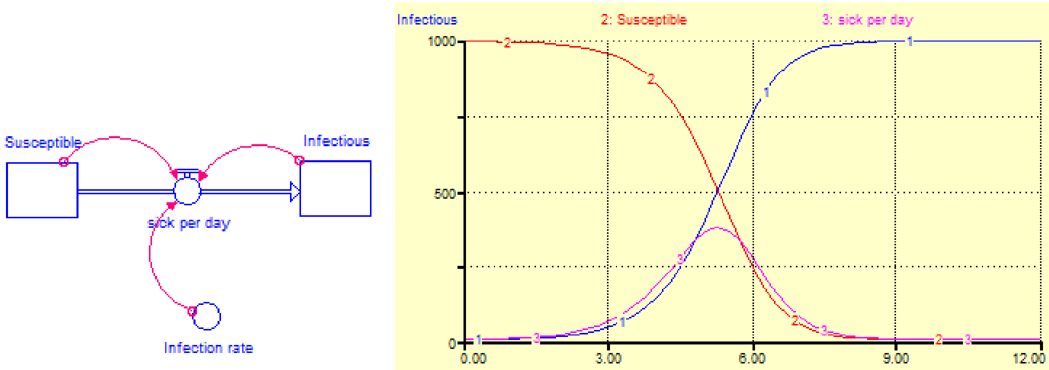


Fig. 2: Simple Epidemics Model with Two Stocks

Simple model requires two stocks: one stock for the people who are not infected but are susceptible to the infection, and another stock for the people who are infected and can transfer the infection. The number of infected increases at a rate proportional to both the number of infected and the susceptible which is represented by the arrows (connectors) connecting each stock with the flow. A separate converter is introduced to describe infection rate which is kept constant during entire simulation. The simple model produces S shaped graph for infection spread representing rapid increase as number of susceptible population decreases to zero, followed by a steady state equal to the total population (Fig. 2).

Simple model creates a good foundation for building more complex epidemics models. In real epidemics infection rates depend on the frequency of contacts between infected and susceptible population and probability of becoming infected. Some people may be immune to the disease and not get infected at all. Airborne viruses (influenza, anthrax, polio, smallpox) have higher transfer probability compared with the ones that are transferred via physical contact (STDs, hepatitis, hemorrhagic fever). Students are required to brainstorm additional factors that may influence propagation of the infection, make reasonable assumptions, develop dynamic hypothesis, and test hypothesis by simulating the modified model over time. More realistic models integrates additional connectors to describe the nature and duration of the disease, incubation time, infection and recovery rates, and development of the temporary or permanent immunity after infection (Fisher, 2007).

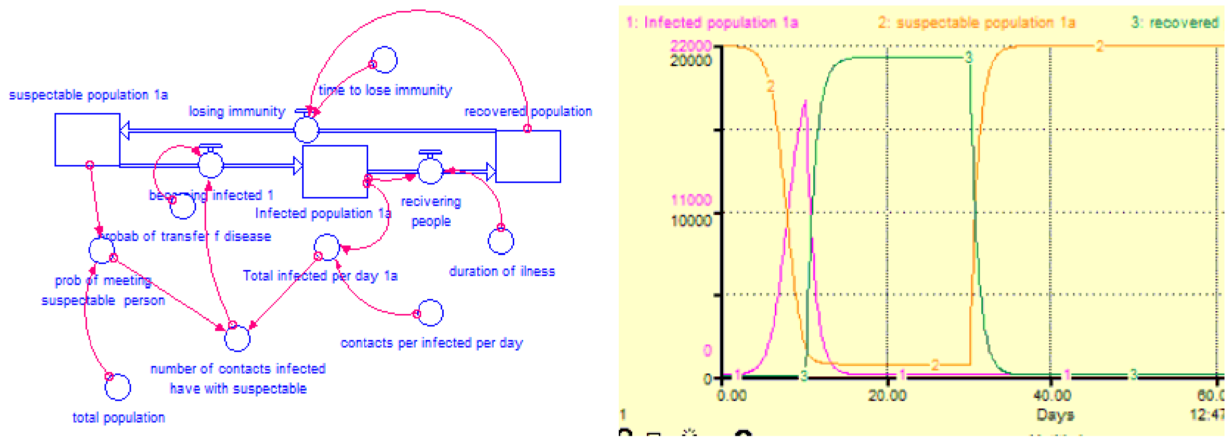


Fig. 3: STELLA Epidemics Model with Three Stocks

STELLA model with susceptible, infected, and recovered population stocks is represented in Fig. 3. This model assumes that recovered people lose immunity after certain period of time and become infected again. As the number of recovered people increases, the number of contacts between infected and susceptible population decreases and fewer people become sick. Students are required to explain possible feedback loops and discuss what happens after recovered people lose immunity. All model variables, assumptions and conclusions are recorded in the laboratory journal along with any modifications made to the simple model. STELLA simulations help students visualize dynamics of the epidemics. Students can increase complexity of the model gradually by introducing additional stocks and converters as needed. Relatively simple epidemics models provide students with clear insights into the factors influencing spread of epidemics. As Bower and Go (2011) indicated, adding complexity does not always increase accuracy of epidemics models since complex models are based on many assumptions that often are not evaluated for the accuracy.

Modeling dynamics of epidemics is a generic structure that can be easily transferred and applied across disciplines due to remarkable similarity among biological, economic, and social systems involving, “infections”, “conversion,” and “market penetration”(Fisher, 2007). STELLA can be used to create money models and explore investment strategies. Creating a simple money model (Fisher, 2006) has been a very popular topic of choice among all majors. Fig.4 represents a STELLA model with four stocks for checking, savings, college fund, and loan accounts. The model includes several depositing inflows and spending outflows along with several inflows for interest income on different accounts.

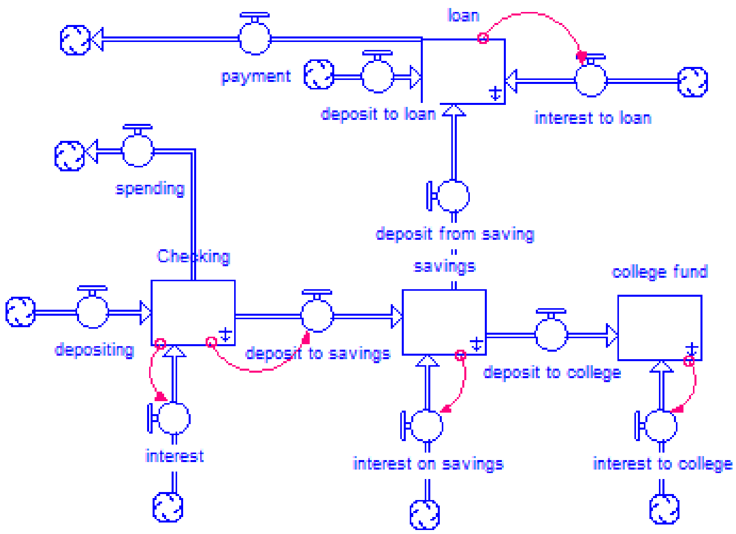


Fig.4: STELLA Money Model with Checking, Savings, College Fund, and Loan Accounts.

STELLA built-in functions allow students to develop individual money management strategies by taking into account their projected income and living expenses. Simulating model over time helps students understand the nature of compound interest and make reasonable decisions about long term investments and managing their own finances.

4. Integrating the American Museum of Natural History as a Learning Laboratory in the CPBL

The American if Museum of Natural History offers number of opportunities for self-directed learning. The Hall of Biodiversity is a learning laboratory and an essential resource for the CPBL. *The Spectrum of life* wall text panels describe global distribution of nine different ecosystems and explain biodiversity of each ecosystem. All living creatures are arranged into 28 living groups (clades) according to their evolutionary characteristics and presented as a graphic chart. Introductory video *Life in the Balance* outlines biodiversity of each ecosystem presented on the wall. Students visit the museum several times to explore different species and their natural habitats in texts, graphics, videos, and case studies. Students work in teams to brainstorm ideas for new collaborative projects. Students obtain all necessary information for their models from the following resources:

- 2,500-square-foot walk-through diorama that remakes part of the Dzanga-Sangha rain forest, one of Earth’s most diverse ecosystems.
- *The Spectrum of Life* evolutionary trip exhibit featuring 1,500 specimens from the smallest microorganisms to terrestrial and aquatic giants.
- *The Crisis zone* representing five major extinction events in the past along with present day species extinction due to human activities.
- *The Transformation of the Biosphere Wall* representing case studies depicting changes to biosphere such as population growth and overconsumption.
- *The Solution Wall* representing case studies with possible solutions to the loss of biodiversity.

Some projects that emerge after exploration of museum resources are: endangered species case, modeling loss of biodiversity, and modeling predator-prey dynamics. Fig. 5 represents core model structure for Lynx (predator) and Hare (prey) relationship (Predator-Prey Dynamics, n.d.).

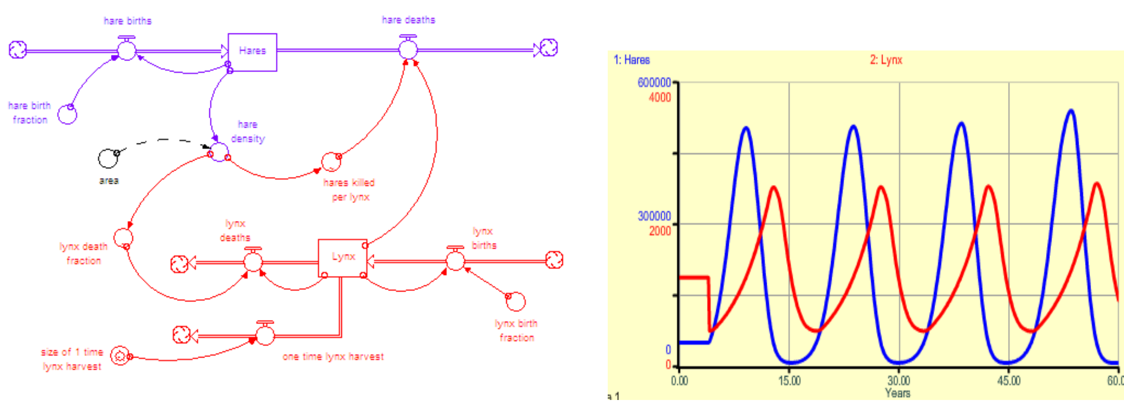


Fig.4. STELLA Model for Predator-Prey Dynamics: Lynx and Hare

This core structure can be easily modified to represent specific cases of any predator-prey dynamics students choose from museum resources. Integrating museum resources into teaching and learning makes learning less abstract and more connected to real world experiences.

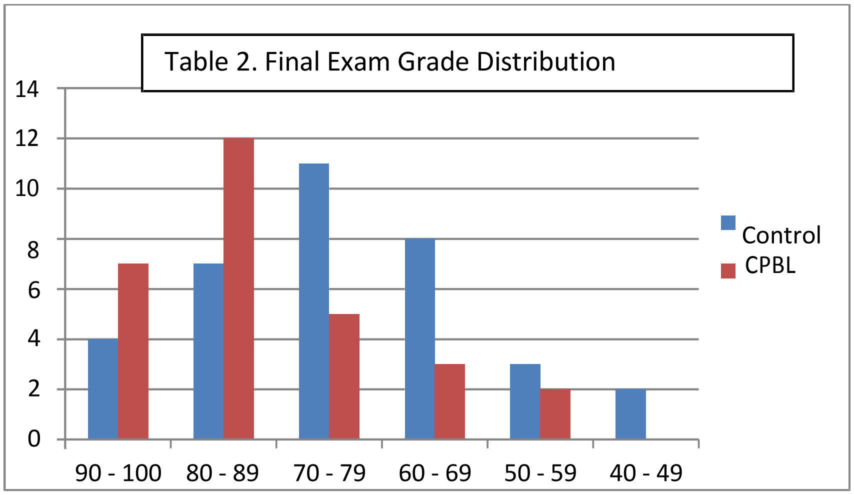
5. Effects of the CPBL on Students Motivation and Performance in Liberal Arts Mathematical Modeling Classes

Student performance scores on the cumulative final exam were collected from two sections of the mathematical modeling course with CPBL component (treatment group) and two sections of the mathematical modeling course without CPBL component (control group). The mean and median grades were 81.52 (B-) and 84 (B) in the treatment group, and 71.49 (C-) and 72(C-) in the control group (Table 1.).

	Mean Score	Median Score	St. Dev	Kurtosis	Sample size N
Control	71.49	72	12.8	-0.56	35
CPBL	81.52	84	10.5	0.064	29

Table. 1. Students' Scores on the Final exam

At a = 0.01 calculated two samples t-test (unequal variance) of 2.967 exceeded the two tailed critical t of 2.666, which indicated the significant improvement in student performance on the cumulative final after incorporating the CPBL in classroom instruction. Table 2 represents final exam grade distribution bar graph for the control and treatment groups. Apart from improved performance, students in the treatment group demonstrated a high level of intrinsic motivation and active engagement. Student satisfaction surveys administered at the end of the course indicated that 87% of students in the treatment group enjoyed class activities and were motivated to learn compared with 72% in the control group.



5. Conclusions

Providing instruction that inspires, motivates, and creatively engages students in the learning process while fostering their own personal growth, intellectual achievements, and academic excellence is a paramount of mathematics education. Incorporating STELLA systems thinking and simulations along with the CPBL in advanced interdisciplinary Liberal Arts Mathematics curriculum creates a meaningful learning experience by fostering scientific and mathematical inquiry, as well as promotes systems literacy necessary to solve interlinked social, political, environmental, and scientific problems. Developing the instruction that bridges the gap between theory and practice by demonstrating widespread applications of mathematics in different fields of arts and sciences improves not only students' performance but also their motivation and engagement in Liberal Arts Mathematics.

Acknowledgement

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