Creativity in STEM Fields

A View from an Eclectic Mind

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This book is dedicated to everyone who taught me to be creative, even if they did it in non-creative ways.

'I daresay you haven't had much practice,' said the Queen. 'When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast […]'

"Alice in Wonderland" by Lewis Carroll

Preface

That day, February 19, 2020, when I attended a lecture and a concert at the Julliard School of Music with a friend, remains in my memory. Nothing could have made me happier than experiencing both venues, a music concert and a research lecture together. Interestingly, I don't remember the concert, but the lecture focused on the neuroscience of creativity, with musicians as the subjects of the research. Classical musicians were compared to improvising musicians using fMRI scans. After the lecture, I spoke with the presenter, requested a copy of the paper (Chan Barrett & Limb, 2019) via Research Gate, and read it carefully on the same day. The idea of scanning creative brains impressed me greatly, and while passionately discussing its implications with a friend, I decided to write a book about creativity in STEM fields. As a researcher of creativity, I could not miss such a chance of being inspired to do something new from something old.

This volume aims to show STEM instructors a path for introducing creativity in the college and possibly high school curriculum. This work is directed to university faculty of math courses and high school teachers

interested in developing their creative skills and bringing elements of creative assignments to their classrooms. This work may be particularly valuable for teachers of non-traditional students who would like to find a way to teach every student individually while encouraging group activities and collaboration. College and high school students may benefit from absorbing the concepts laid out here and expanding them for their purposes.

This volume seeks to fill the gap in the existing literature and addresses the need to carry creativity in STEM in collegial education. This work is based on my first-hand experience as a researcher in a community college. I have focused my class activities on incorporating creative research projects into the college curriculum in the classroom and outside. Amazed by the different attitudes displayed by students while working on research-oriented projects that contained creative elements, I decided to incorporate creative projects in my classrooms. This placed me on the path of discovery of my own creativity, which sparked my enthusiasm for pedagogical work. This changed how I teach, think, work, and research. This changed the way I live. Most importantly, emphasizing creativity shifted the importance of learning from learning a particular subject of mathematics to incorporating that subject among previously learned subjects, making a fine mind structure.

We all need to be creative daily to move our reality towards progress. The education that we are offering today should reflect the fast-changing digital era we are currently living in. Today, science and technology are growing faster than ever, supported by analyzing terabytes of data that can fit on a tiny device. It does not take much to understand that we simply cannot predict the future needs of our students. That is why we should teach them how to be creative and hope that this little knowledge they learn at school gives them a basis for further growth.

It is important to understand that only a teacher who treasures a creative thought can successfully teach creativity to students. Thus, before preparing the first creative class assignments, the initial stages of the path contain self-awakening of creative thoughts within topics not necessarily well known to the reader. May the path to creative thought begin for the reader with the purpose of re-shaping college education.

I would like to study various paths of awakening creativity among readers for future research. So, stay tuned to yourself since I want to hear from you and learn how you made it into the creative side of your mind. Please send the report with the answers to book questions, your comments, and reflections on the process to my email address, malgorzata.aneta.marciniak@gmail.com, with the subject line: Creativity in STEM fields.

For whom is the book written? Initially, I had college and high school teachers in mind because I was familiar with the challenges of this group. However, in the process of writing, a colleague of mine suggested expanding the audience to include college and high school students. After giving this idea a few thoughts, I have realized that open-minded students may benefit from this book just as much as their teachers, or maybe even more. Moreover, the students will carry their wisdom into the future, to which I do not have access. Thus, I will take students' presence in the audience as an extension of this idea to the future.

I often ask myself to be more specific and visualize those teachers and students to whom the book may be addressed. When I close my eyes, I see those who really need to uncover or discover their creative vibes to improve their daily routines or the quality of their internal dialog.

Thus, I imagine teachers who go to class and apply their heart to teaching and are deeply moved by the observation that students are not learning.

The book also has in mind a student who wants to expand their learning beyond the school curriculum and beyond the conventional educational paradigms. This process is particularly painful in traditional mathematics classrooms, where mathematical ways of thinking are imposed without giving any reasoning or any inquiry. What are the reasons for this shortage of creativity in the math classroom? Or is it not only math and school but something more fundamental? This question may require some elaborate reflections. Rollo May in his book “The courage to create” (May R. , 1975) points out that the shortage of creativity has its roots in a basic fear of discovering the truth about one’s nature. However, at the same time, it is dangerous to discover the gaps in reality created by one’s family, job, town community, or the entire society and the government. Add social media, a group of friends, or coworkers to discover that in every stage of individual growth and evolutionary growth of the human population, someone is imposing some view of reality on others. Moreover, others were imposing on someone. This mental inbreeding is very visible in the mentalities of little towns or small societies, where a small click of individuals mirrors each other's frame of mind, narrowing it with every step. I always thought the problem with the shortage of creativity was in the minds’ laziness and obedience to accepting well-traveled paths. However, now I see that this view is a mere oversimplification. The survival mechanism prefers a delicate balance between obedience to the group reality, creative vibes imposed by necessity, and a sense of wonder. Rollo May discusses the intensity of the encounter of creative vibrations. He points out that in the blunt realm of daily routines, the moments of creative insight shine like diamonds. They carry the power to erase bad memories and the power to heal anxiety, trauma, and accumulation of disappointments. In a search for sparks, I keep trying and going from one project to another, never satisfied and never filled, always hungry and always searching for more and beyond. However, what may appear to be a monkey mind is more like a driving force, a consistent and persistent desire to expand and grow the

mindset beyond and beyond the sea of known. When the mind becomes temporarily filled with content, it must write or speak, or it will blow up, collapse, and then resume after a moment of decay. Sounds familiar? Rollo May discusses the necessity of alternating between work and relaxation to encourage creative energy. In the middle of profoundly engaging work, take a break and relax; in the middle of relaxation, dive into the burning questions of why and how. Who would have expected this little book by Rollo May, which I picked up randomly at the Graduate Center library, to prove so insightful? Moreover, I cannot believe my reasoning for choosing this book, not another book, was silly. I got it because it simply fits in my tiny purse, and I could read it on the subway. Small is beautiful! Coincidentally, Rollo May quotes Poincare (Poincaré, 1914) to justify why this and no other ideas are picked from the vastness of the subconscious mind, giving an argument for beauty. I would add the saying that beauty is in the eye of the observer, meaning that out of the unbounded, one's consciousness picks those messages that are somehow tuned to it or fit in the opening. It may be an answer to a burning question or an idea that solves a disturbing problem. Alternatively, he roughly pretends to do that with a certain approximation. Here, we are examining the challenging aspects of creativity in STEM fields. They all have the same features; they are far from "natural" inquiries of the human mind that revolve around the state of the heart of daily routines or the beings around. Giving an example from mathematics, most math inquiries are buried underneath mathematical notation, terminology, and previous discoveries of generations of mathematicians. Thus, the opening for mathematical discoveries must be skillfully and consistently encouraged as it will not likely appear spontaneously in most minds.

The book is structured in the following way:

After a chapter on motivation, there are chapters about the definition of the stages of creativity, as in Wallas (Wallas, 1926) and Csikszentmihalyi

(Csikszentmihalyi, 1974). The examples assist the definitions of stages. Chapter 3 contains a creative dispute regarding the position of creativity in Bloom's taxonomy. Chapter 4 consists mainly of developmental theories for children's growth, according to Piaget (Piaget, 1952) and Vygotsky (Vygotsky, 1978), and for the mind organization of adults, according to Kegan (Kegan, 1982). Since I did not imagine that teachers who do not facilitate their creativity could successfully facilitate it in the classroom, thus some advice on self-development of creativity is presented in Chapter 5. Chapter 6 contains ideas for research projects for various subjects, while Chapter 7 includes sample classroom assignments. Ideas for assessment, inspired by the Torrent Test, are in Chapter 8. Since reflections are very important for the growth of creativity, chapter 9 includes reflections from the times of the pandemic, which, in my opinion, tested the capacity of the teachers for creative ways. Chapter 10 consists of reflections on the path and possible ideas for future work. Each chapter is assisted by a suitable picture among paintings traditionally attributed to Tenshō Shūbun (天章周文) (1414-1463) and verses by Kuòān Shīyuǎn; translation by Senzaki Nyogen (千崎如幻) (1876–1958) and Paul Reps (1895-1990), https://en.wikipedia.org/wiki/Ten_Bulls

In Search of the Bull

In the pasture of the world,
I endlessly push aside the tall
grasses in search of the Ox.
Following unnamed rivers,
lost upon the interpenetrating
paths of distant mountains,
My strength failing and my vitality exhausted, I cannot find the Ox.

—1—

Can Creativity be Taught and Learned?

This chapter is dedicated to those who may doubt whether STEM education can accommodate creative activities. I will explain whether creativity may be taught and learned in the classroom. In my opinion, creativity can be facilitated and, if encouraged, may flourish. Facilitation of creativity does not guarantee that everybody in a classroom will arrive at some creative ideas, but it opens space for some students to develop creative thought.

When asked about the factors contributing to success in math classes, my students frequently mention talent as the most important. Similarly, it is expected to think that someone is or is not creative, and creativity does not significantly vary throughout someone's life. While an instant transformation from an entirely non-creative mind to impulsively creative does not sound realistic, a gradual work on the skills, the subject of this

volume, is possible. Since working with the students' minds is a daily activity for all teachers, I am proposing gradual changes to more creative approaches. Due to the plasticity of the mind (Marzenic, 2013) this task can be accomplished.

Evolutionary necessity

Regardless of popular stereotypes about the need for creative vibes during human evolution, I suspect that creativity has been a necessary skill since the inception of humankind. That is probably because fate is inventive in bringing unexpected circumstances and new challenges. Even in our highly predicted daily routines, the next day is not a mere copy of the previous day, always carrying something new. Going one step deeper into the reflections about the need for creativity in daily life, one can state that creativity has been the sole property of the human mind. One may inquire whether it enters the minds of other species since they also experience challenges and caprices of nature. It is true that monkeys and certain birds use tools (sticks or stones) to open nuts. Moreover, they can indeed teach their offspring such skills. However, do they reflect on the process of creation or teaching to such an extent as we humans do? I will claim that creativity is a unique property of the human mind and significantly contributes to the evolutionary success of our species. It seems that for the survival and well-being of human society, not everybody needs to be highly creative since just a few individuals make spectacular creations. However, the truth is that we all are performing small creative acts daily, often not even fully realizing them. Creativity is not only the activity reserved for the learned, the artists, the poets, or the engineers. It is a common thing to be creative. However, being aware of the creative process and being able to improve one’s creative skills are more subtle. Hopefully, this volume will help build such awareness by offering insight into developing the process of self-improvement to introduce creativity in a college or high school STEM classroom.

In 1964, Kuhn formulated a theory of scientific revolutions (Kuhn, 2012), which briefly can be described as alternating gradual and rapid changes in the growth of sciences. Moreover, Kuhn emphasized the incommensurability of the quality of accomplishments performed within the frames of different paradigms. It is worth noting that revolutionary changes are not exclusive to political or socio-economic human history or the growth of sciences but are frequently observed in nature as giant stellar collisions or mass extinctions of species on Earth. Multiple attempts have been made to dispute, modify, or generalize the original idea of scientific revolutions, for example, in education. In the light of that concept, Ellis and Berry (Ellis & Berry III, 2005) discussed the paradigm shifts in mathematics education in the USA related to what is meaningful in mathematics and how it should be tested.

What is significant is that the past pivoting moments were happening more sparsely, with the spans of 60-80 years for the times of secular or compulsory education or 10-20 years for the times of “New Math” and “No Child Behind Act.” However, the two revolutionary changes that took place very recently, the pandemic and the appearance of chatbots, happened close to one another. The pandemic that lasted worldwide roughly between March 2020 and March 2022 was created by nature. The appearance of an advanced chatbot took place in November 2022 and was entirely developed by humans. Since all things in the universe are inevitably connected, there is a possibility that the extended time of the pandemic put a sprout on the appearance of advanced chatbots due to the excessive spare time of researchers or hiring a larger than usual number of programmers simultaneously. Based on that observation, one can conclude that due to the accelerated speed of growth of technology and human development, paradigm shifts will take place more frequently in the future than in the past. This will affect the shape of education and impose a strain on educators. Education must reformulate some of its paradigms to accommodate the expected changes and the frequent

appearances of pivoting moments. Without revisions, education will become outdated and eventually reduced (just like other unaligned things in nature), marking the beginning of the end of our civilization. Thus, creativity in education is an evolutionary necessity.

Can Creativity Spark the Experience of Mathematics?

Why should we even attempt to teach students some entirely useless skills? Unfortunately, that is how math students (and teachers) often feel. The rigid formalism of mathematics is considered the highest accomplishment of generations of mathematicians, and their work across the globe and throughout centuries has become the curse of the school subject. This rigor of mathematics exposition became a nightmare for students and a source of anxiety for many. Where does the anxiety come from? How often did teachers hear from students that they studied for the entire night, and everything disappeared from their memory while taking an exam? Similarly, students usually claim that they know how to add and multiply numbers, but they cannot execute these rules correctly every time.

While many teachers may not believe in the honesty of these statements, I do believe them since I have experienced similar symptoms. It is not uncommon for me to forget everything when I am emotional. Being angry or hurried suddenly erases my memory of facts and skills. Trying to do calculations after being punched in the nose will not likely lead to the correct results. This strategy of the mind in a dangerous situation of emptying itself from all irrelevant knowledge is an evolutionary function. This helped our ancestors think quickly and clearly to survive, but the same strategy applied during a vital exam may lead to a complete failure. Thus, a frustrated student who fears that during a quiz they will likely forget everything learned the previous day.

I remember a research meeting with two skillful and experienced colleagues when we were sitting in a coffee shop and solving math problems from our research seminar. We arrived at the point where we had to perform specific calculations requiring basic algebraic skills. However, the level of complexity of the expressions was so high that we spent the entire hour before we agreed on the results. Then we confirmed it with software, laughing at ourselves and our sloppiness, but this made me think that knowing the rules and consistently applying them correctly is not the same. Should we then grade math students for perfect correctness of their calculations? If not, then how should we grade them? Are there other ways to assess students' progress? Can modern education use them in determining students' course grades?

However, shall we drop entirely the arithmetic skills of applying basic rules over and over and rigorously executing them? In my understanding, a person who cannot follow basic rules of addition and multiplication should not be expected to perform skillfully on other tasks of modern life, such as following the Traffic Laws, Tax Rules, or Voting Policies. A giant metropolis such as New York City has complicated rules to follow daily, and even using a subway pass requires specific skills of following the guidelines carefully. Some may argue that mathematics is boring and that doing meaningless calculations with no purpose or goal is tedious. Moreover, I agree that students' interest, involvement, and enthusiasm can give meaning to any subject. Thus, motivating involvement has been a challenge for generations of teachers all over the globe. However, improving students' involvement in math classes remains an unsolved problem in its full generality.

In my classes, students frequently request applications of mathematical concepts that appear in class. However, when the time of the test comes, they beg for not having those application problems on the test. After realizing that pattern, I concluded that in math courses for engineers, there

is a vast selection of engineering students who do not feel comfortable with applications from other areas of engineering. Thus, civil engineering students strongly object to applications with circuits, and electrical engineering students despise applications in statistics. To resolve that issue, I have introduced applied projects in my classes, where students can select their favorite topics or create their projects. In my understanding this technique improves both, students' involvement and creativity.

Is a STEM classroom a good place to (re)learn creativity?

While visualizing a creative person, we may have in mind an image of an individual artist (or a scientist) going through creative processes in the solitary atelier. Still, discussions with peers and their suggestions, appreciation, or words of criticism are crucial in a creative process. In other words, in creativity, "no man is an island entire of itself." I recall that many interesting research conclusions were revealed during interactions with others. My most enlightening observations arrived when I was observing others, for example, my students, who were going through creative processes. These observations proved to me the significance of a social experience of creativity. I think the intensity of the creative process experience may be so absorbing that self-reflection and self-observation may be limited. Thus, observing others during that process may be a crucial aspect in the growth of self-awareness of one's creativity. That is why, in my classes and during research meetings, I encourage students to work in groups and share their experiences related to their thinking processes. In my understanding, we often imitate and later adapt the new skills of the mind after observing them in the others. Thus, learning the skill of creativity in a classroom may be improved by collective experience shared by groups of peers. This aspect of creative work should not involve competing with others but can contain nonjudgmental comparisons of the stages of the creative processes among the researchers. This aspect of

creative work should solely focus on building awareness and sensitivity to the creative signals. I believe that the social experiences of the creative process may be a natural way to grow creative awareness since humans tend to be highly sociable creatures who enrich each other through encouragement and shared experiences. My impressions are supported by research in neuroscience related to mirror neurons (Ramachandran, 1995).

The role of mirror neurons in experiencing creativity in a group

Mirror neurons were discovered in 1992 by Giacomo Rizzolatti and a group of researchers in Parma, Italy. They have the property of firing when one performs an action and when one observes that action being performed by others. (Keysers, Kaas, & Gazzola, 2010). Even if the role of mirror neurons remains disputable among neuroscientists (Taylor, 2016) this discovery leads to various hypotheses about the possible roles of the mirror neurons in cognitive processes, particularly creativity.

Following the concept of the “imitative” function of mirror neurons (Pineda, 2009), one may inquire about their roles in the processes and flows of creativity. Claiming that mirror neurons play a role in a learning process supports the idea that while teaching the material, we also teach our students some mental processes and attitudes connected to it. For example, our love of mathematics may be contagious and spread out to some individuals. Thus, we should expect that once exposed to other individuals experiencing creative cycles and flow, our students have increased chances of experiencing such a flow independently.

I wholeheartedly support the idea that observing others while they experience creative processes is of excellent value to the observer. That is because my interest in creativity was initiated by my observations when working with students on creative research problems. I realized that

students behaved differently and carried different attitudes when working in my office on creative math problems than when they worked in a classroom on mundane assignments. I have no doubts that this curiosity, which grew in me over time, was detached from self-awareness and entirely rooted in observing my students. In my understanding, there is a lot to research about the role of the influences of social experiences on the creativity of individuals.

Practice of experiencing creativity in a group

The pandemic sometimes gave me surprising insight into creativity. I discovered that the group does not have to meet in person for the individuals to experience the power of mirror neurons. The excitement and enthusiasm can be passed across space and time without losing intensity. We all experience it while reading an exciting book written by a person passionate about their work and discoveries. Modern technology and its vast availability of free networking make sharing more accessible than ever. In my classes, when introducing assignments for creative projects, I frequently use examples of work performed by students from previous semesters. For the first time, when presenting the projects in the classroom, I used an example of students' work from a mentored research project. Usually, I display the slides and show a video pointing out what is valuable and significant about students' presentations. For example, recently, my students in the Differential Equations class found articles about designing loops of roller coasters and prepared a quality presentation with a historical background and multiple details related to various designs of the loops. Finding a topic was a creative assignment since students read the guidelines and reflected on their interests, connecting them with the material learned in the classroom. This presentation will be shown to students next semester as an example of an excellent choice of topic. It will encourage students to search for

something exciting. Students who prepared the presentation about rollercoasters wrote in their self-report about creativity:

“After doing a significant amount of research, our group had a blast learning more about how these attractions worked, more specifically, the loop aspect of the rollercoasters. It would be insane to see how these engineers create other inversions that are more complicated than the shape of these loops. The concepts used in this project mainly came from physics, but it was cool to see differential equations take a role in helping determine the shape of the loop itself. This project also was an eye-opener to show us that these engineers must work carefully as they are responsible for the lives of people that dare to embrace the thrill.”

An attentive observer could see that one student infected others with his idea, and they got excited about it just as much as he did.

Creating groups based on a diversity of skills

Often, as teachers, we struggle and complain about the body of students in the classroom being highly diverse in terms of students’ preparation, dedication, and skill levels. I can relate to it and agree that the homogeneity of the classroom makes lectures more aligned with students’ needs. However, in the case of creative assignments, the situation is quite opposite. Diversity in a group offers a chance to exchange the results of creative assignments and the entire creative thinking process with its errors, reflections, and corrections. Thus, I encourage students to collaborate based on diversity while facilitating creative assignments.

This aspect of work is closely related to experiencing creativity in a group but focuses on experiencing it within a non-homogenous group. At the beginning of the semester, my students receive a sheet with self-assessment questions about their level of skills: math, language, collaboration, and public speaking. Bringing these particular skill

categories is justified by my observations and assessments from previous semesters. In my classes, students may represent highly varied levels of math skills due to their diverse backgrounds. In addition, some students return to college after a long absence and may not feel comfortable with all studying skills. Reading, writing, and public speaking are categories motivated by the fact that a significant percentage of the student body consists of non-native speakers. The range may be ample, containing students who just arrived from abroad and, for example, can read and write excellently but have serious difficulties speaking English. Some students may have completed American high school, but English is not their first language, and they do not use it daily. These students may lack some language skills but be firm in others. During the semester, students are encouraged to observe these skills among other students and attempt to compose their project teams based on the complementarity of the skills, not on friendships, race, gender, or such.

I have observed that students with creative ideas either prepare the projects independently or compose their project teams easily according to their own needs. However, students who do not have innovative ideas and were not chosen to complete someone's team struggle with decisions about their topic and have difficulties delivering a quality presentation in a timely manner.

To support my students' collaborative skills, I mention in class that the most valuable creative environment is formed by the free flow of information among researchers representing various areas of expertise and multiple levels of insight. While working with students on mentored research projects, I found their naïve attitude particularly valuable. As I noticed, students often try to work on exciting ideas. At the same time, professors' expertise and experience of previous unsuccessful work on such ideas made us lean toward the direction of accessible problems. This dual approach usually places the team within the scope of exciting projects that

are workable and publishable, not only conversational for a theory or hypothesis.

The role of the teacher

How much should the teacher be involved in the creative process? In my understanding, it is sufficient to show students how to start the project and then influence the work as little as possible, ensuring that students enjoy the process and keep progressing in understanding and growing creativity.

At the same time, I do not visualize someone without excessive experience in the creative process trying to facilitate such a process for others. Working on my research and doing creative artwork significantly improves my skills as a facilitator of the creative abilities of others, in this case, students in my classes and students who work on research projects with me. To summarize my experience with creative assignments within the curriculum and beyond, I would say that everyone needs to find a unique way of implementing creativity in their work and daily life.

Classroom creativity supported by brief creative assignments

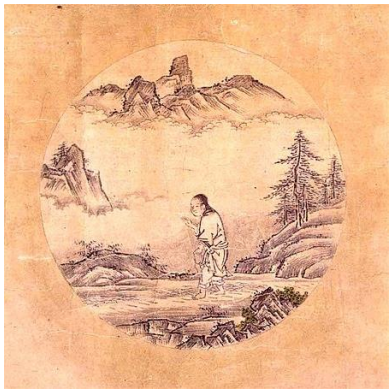
This momentary experience of creative thought can be facilitated in a classroom even with little time and equally little effort from a trained teacher. A brief assignment is supposed to be short in preparation, quick in performance, ungraded, or low stakes. Students should not feel that they are evaluated or judged during such assignments. But even a light smile or a teacher's blink may reveal to the students the accuracy of their answers. The primary purpose of brief creative assignments is to provide a feeling of immediate response, which cannot be incorrect. That is why it is good to focus on how students think rather than what they produce. Examples of brief assignments can be given at the beginning of each topic when students do not know and are not supposed to know the correct

answers. They are not expected to display a proper way of thinking but to wander around the idea randomly and report on what comes to their mind based on free associations. The reward of a diverse classroom is that students can compare their possibly incorrect answers to gain a view into other students' minds. Reflecting on a comparison of these answers provides insight that is unavailable to lone learners. It is always rewarding to have sequences of such brief assignments to, for example, justify why a uniform notation is necessary in mathematics.

Classroom creativity supported by research projects

It is a real challenge to match students with topics. The topics for my favorite project (Geometry of Solar Panels) were determined based on informal discussions among students and me. The story began when two of my classes were scheduled consecutively in the same room where I would stay during the break. Somehow, two of my students would come early to class and chat with me there. This way, we developed favorable initial conditions for free time and uninterrupted conversation space. Starting with very casual topics about neighborhood coffee shops, we swiftly shifted to our favorite books and movies, followed by what we would like to work on. One student mentioned that she would like to work on a project connecting the calculus she learned at college and her passion for civil engineering and architecture. She wondered whether wrapping an entire building with flexible transparent solar panels would be reasonable. I responded that it would be very wasteful because the position of the panels toward the sun determines its efficiency. Thus, the part facing north may not be as efficient as in other directions. We wanted to determine which shapes are efficient and how to position flexible solar panels toward the sun for the best efficiency. Later, those students became the best advertisers for my projects and classes. Walking around the college and displaying their enthusiasm related to learning mathematics in the context

of research projects, they convinced other students to do the same. Many students walk into my office to inquire about the possibility of working on projects together and often report that they do not expect research projects to be offered at a community college. This shows the necessity of a specific advertisement for the research projects.



Discovery of the Footprints

Along the riverbank, under the trees,
I discover footprints.
Even under the fragrant grass,
I see his prints.
Deep in remote mountains, they are found.
These traces can no more be hidden
than one's nose, looking heavenward.