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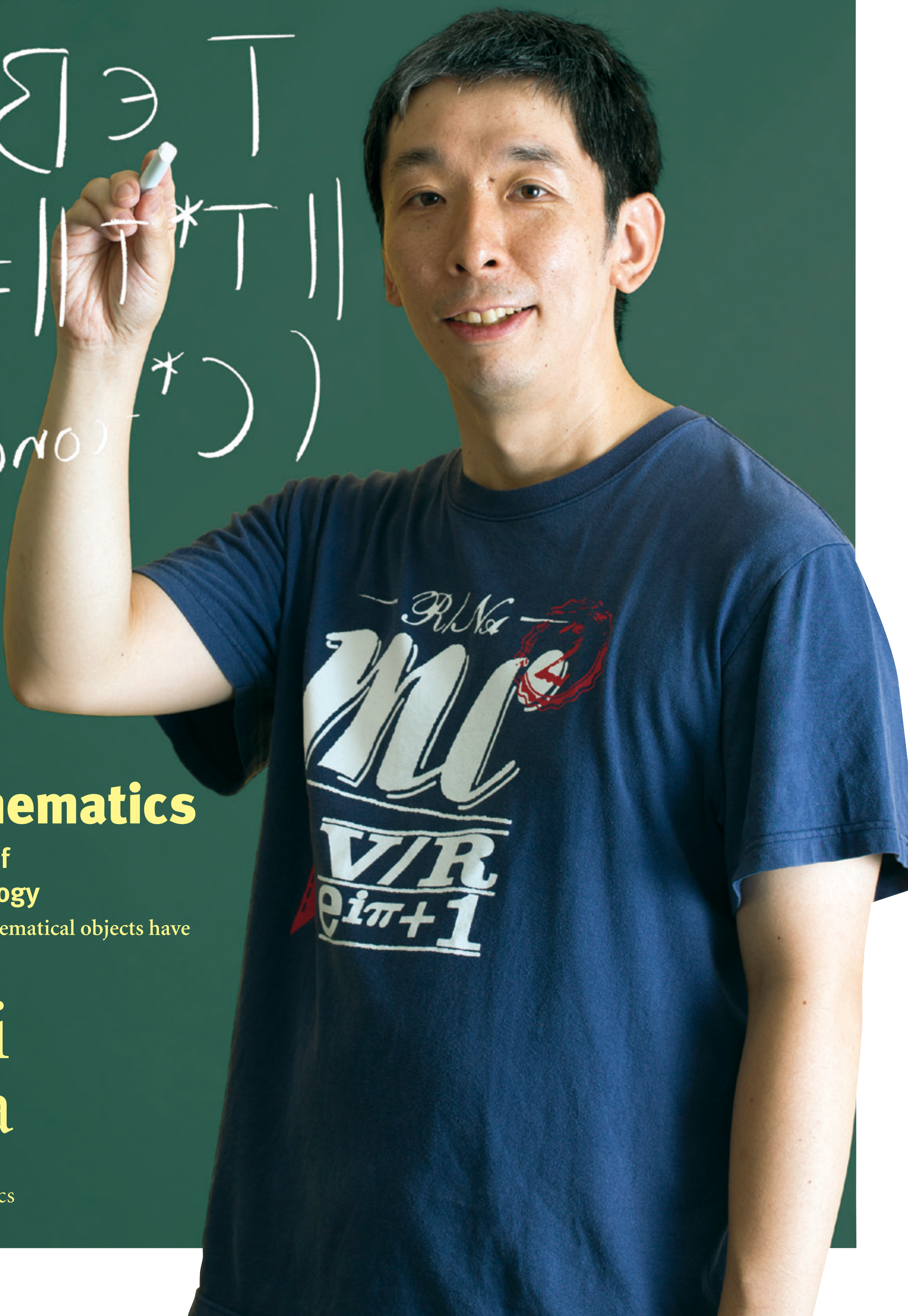


Pure Mathematics

from Keio's Faculty of Science and Technology

In quest of truth that mathematical objects have

Takeshi Katsura

Associate Professor
Department of Mathematics

Associate Professor Takeshi Katsura is Featured in this issue, whose field of research focuses on the theory of C*-algebras, a field of pure mathematics.

The fundamental motivation for mathematics lies in "Beauty"

What is the attraction of the pursuit of pure mathematics?

Of the many academic disciplines, mathematics is one of the most indispensable as the foundation of our civilized society but is perhaps the least understood by people due to its breadth and depth. Particularly, the field known as pure mathematics – which is in the opposite end of practical sciences – is a world extremely hard to see and a world that only a handful of specialists can deal with. For this issue, we asked Dr. Takeshi Katsura about the attractiveness of and his approach to pure mathematics, and some of the theory of C*-algebras which is his specialty.

Solving problems is not all about pure mathematics

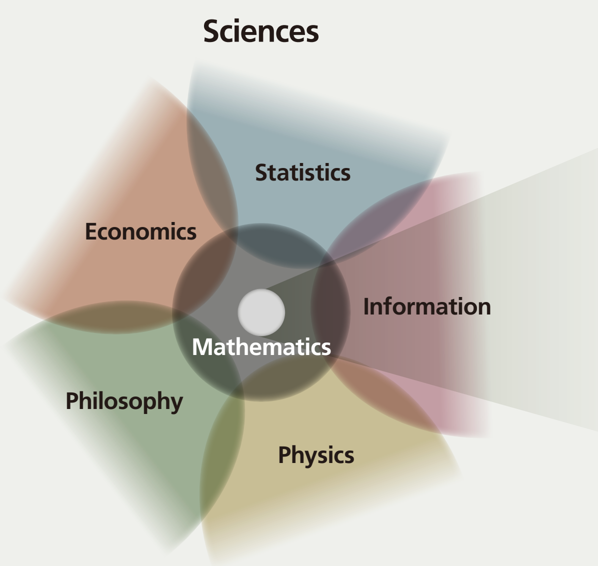
We sometimes hear of news bandy around like this, "A mathematical problem, which has been unsolved for centuries, has been solved at last!" But it is often the case that understanding how such a difficult problem was solved is extremely difficult even for specialists and can take years to examine whether the proof is correct. Such is a hard-to-understand aspect of the world of pure mathematics. Then, how are mathematicians solving problems?

"Of course I admit that solving problems is the mainstream of endeavors for studying pure mathematics. On the other hand, in pursuing studies we mathematicians rarely experience solving a problem truly worth solving. This is because many of the problems that remain unsolved by humans are either totally worthless or ones too difficult to solve. It is also true that too difficult a problem to solve is not always well worth solving. Many scientists then scrutinize the value of a solved problem and its results over a period of many years. It can also happen that results of abstract pure mathematics studies are unexpectedly applied to practical uses after a century or two. That's why I think we, researchers of pure mathematics, must establish and maintain values and an aesthetic sense of our own that are not affected by others and yet sympathized by them," emphasizes Dr. Katsura.

If solving problems is very difficult as he says, then what are mathematicians advancing their own research for, and how?

"In the study of pure mathematics, I think much of our efforts are directed toward finding curious phenomena and understanding them, rather than simply solving problems and finding answers. To do so, we must thoroughly investigate the object, build a hypothesis and verify it through experiments. This approach seems similar to approaches taken in the engineering field. What characterizes pure mathematics is that our targets are abstract mathematical objects. Another characteristic is that we basically take an approach that we term 'thought experiments' although experiments often depend on computers."

He continues, "No matter how acceptable an answer appears, it cannot be considered to be the 'result' unless it is proven properly. This is still another characteristic of mathematics. Suppose you have found a phenomenon to be proven but are unable to prove it. In that case you may publish it in the form of a conjecture, but even so it is regarded as an important research achievement in mathematics. Some day in the future, I'd like to publish a conjecture that would lead mathematical studies of the world. Of course, it would be best if I could prove it."



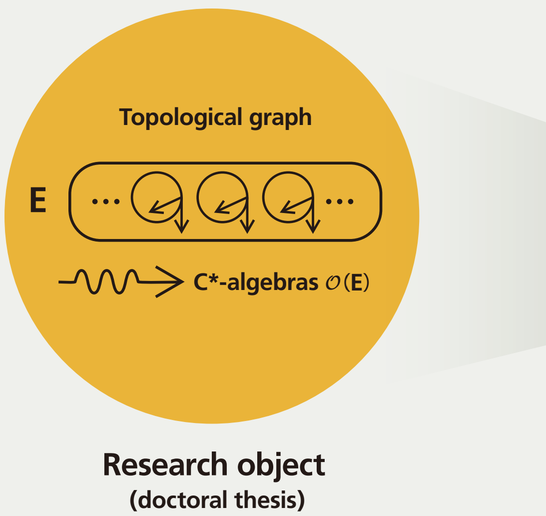


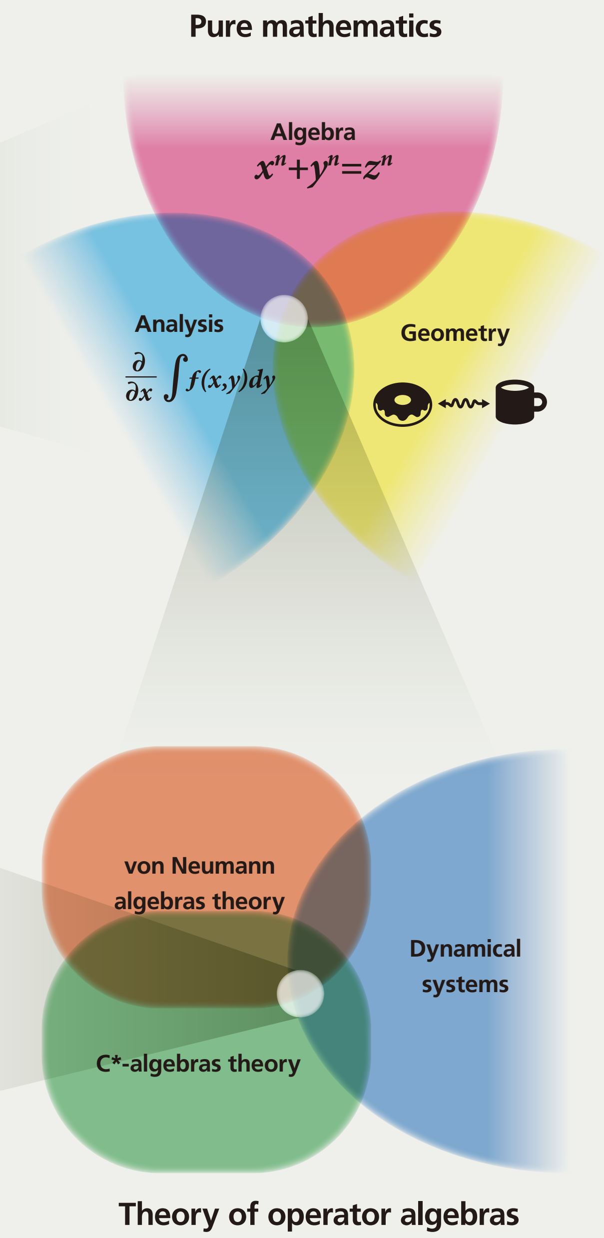
Fig. The positioning of Dr. Katsura's doctoral thesis and related fields

Generally speaking, mathematics is related to diverse fields, but Dr. Katsura's specialty is "pure mathematics" seemingly having little to do with the other fields. Yet, he maintains an interest in aspects of pure mathematics that are concerned with other fields. In his doctoral thesis, he introduced a new perspective into an area where "C*-algebras" in the theory of operator algebras meet dynamical systems related to physics. He is now becoming more interested in set-theory-oriented mathematics, a field said to be close to philosophy.

Noticing structures of sets and examining their relationships

How is it possible to investigate into mathematical objects that are both invisible and intangible? The keywords are sets and structures, according to Dr. Katsura.

"When asked about the most familiar mathematical objects, everyone will answer they are numbers such as natural numbers, integers and real numbers. In investigating into numbers, there is an approach: to collect and examine a set of all numbers that satisfy certain properties, instead of dealing with each individual number. In mathematics, we call a collection of such mathematical objects a 'set.' For example, a set of all natural numbers is represented by N, which is an infinite set. On the other hand, a set of all real numbers, R, is often expressed as a number line."



"These sets of numbers naturally have their own 'structures.' For example, a number line as an expression of a set of all real numbers, R, is considered to express structures such as a 'relation' for two real numbers – which is large and which is small – and a 'metric' between the two numbers. Besides these structures, sets of numbers have a structure known as 'operations' that involves addition, multiplication and so on," Dr. Katsura mentions.

He says it is possible to shed light on the very structures by describing these various types of structures in set-theory languages like mapping (*1).

"Each time we notice a certain structure, the set having that particular structure becomes a research object in mathematics. For example, the structure 'metric' leads us to concepts such as metric spaces and topological spaces (*2), which are the objects of geometry. Likewise, the structure 'operations' involving addition and multiplication leads us to concepts such as "groups," "rings" and "fields" (*3), which are the objects of algebra. In today's pure mathematics study, it is common to look for instances of such mathematical objects and investigate into relationships between properties shared by such objects and those between different objects," Dr. Katsura continues.

In particular, Dr. Katsura shows a special interest in and focuses on relationships between objects of different structures (ring, metric space, etc.) and objects having multiple structures (group, topological space, etc.) at the same time.

"Up to now I have focused on the object called 'C*-algebras' (*4). In addition to structures such as metric spaces and rings mentioned earlier, C*-algebras also have structures called linear spaces and '*' (star) and satisfy various conditions (*5) among these structures. While intriguingly interrelating with other objects such as dynamical systems (*6), topological spaces and fields, C*-algebras are being studied even today. I personally regard C*-algebras as very charming, but I cannot explain it in compact, easy-to-understand expressions. Because easy explanations often come with incorrectness and falsehoods, you know," says Dr. Katsura smilingly.

I'd like to open up a new horizon of mathematics by challenging boundary areas

What meaning does Dr. Katsura find in studying the highly abstract world of mathematics? "For me, the foremost motivation is that I feel 'beauty' in there. In fact, while I'm wrestling with a question, there happens to be a moment when I find a truth that I feel truly exquisite. In the 19th century, mathematicians discovered an extremely beautiful area of mathematics called complex analysis (*7). In the 20th century, this complex analysis played vital roles in mathematical description of quantum mechanics by von Neumann and others, the results of which have supported our modern society through semiconductors. In this manner, it is often the case that truly beautiful mathematics can find unexpected applications after many years. I'd like to leave such a significant achievement to posterity myself," talks Dr. Katsura eagerly. He also expressed prospects that he would like to pioneer yet unexplored fields of mathematics by expanding his research objects beyond C*-algebras to cover boundary areas of dynamical systems, number theory and set theory studies.

(Reporter & text writer : Madoka Tainaka)

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*1: In mathematics, mapping refers to a rule to assign to each element in one set a particular element in the same set or in another. For example, addition can be described as mapping from the set of all pairs of numbers assigned the sum of each pair.

*2: The term "topology" in mathematics totally differs in concept from "phase" that concerns with waves and other phenomena.

*3: Roughly speaking, the "group" refers to objects with a structure of addition, the "ring" refers to objects with structures of addition and multiplication, and the "field" refers to objects with structures of the four arithmetic operations including division.

4: C-algebras are one of what are called operator algebras. The other type of operator algebras is von Neumann algebras named in honor of John von Neumann (1903~1957), the father of the operator algebras theory. The theory of operator algebras was created in the 20th century for the purpose of formulating quantum mechanics mathematically. Operators are something like an infinite matrix and operator algebras are rings consisting of operators.

5: Of the various conditions, the condition $\|T^*T\|=\|T\|^2$ is called the C-condition. It is a magical and important condition enabling C*-algebras to work as operator algebras.

*6: Dynamical systems are used to describe time evolution of states, which are a field of mathematics born of physics just like operator algebras.

*7: Complex analysis is something like replacing real numbers with complex numbers that we learned in high school calculus.

Taking up the pure mathematics career led by friends I met during the Math Olympiad, and by my respected teachers

Dr. Katsura says he was first induced into mathematics by friends whom he met during the Japan Mathematics Olympiad and studied together with them before choosing the career of a mathematician. Later, he met co-researchers from other disciplines and teachers under whom he would study. In addition to these assets, also supporting Dr. Katsura, now as a researcher, are various valuable experiences he gained in Japan and overseas as well as his family.

What was your childhood like?

I was born and raised in Muko City, a so-called "bedroom" suburb community in Kyoto Prefecture. My father was so fond of board games and puzzles that all sorts of playthings, such as Othello and backgammon (board games) and Rubik's Cube, were everywhere in my home, with which I used to play almost everyday in my childhood. It was customary that I enjoyed board games together with my family members.

We guess you were good at arithmetic since childhood, is that right?

I was good at arithmetic but not at calculation at all. Even today, calculation is my weak point. What I liked were puzzle-like problems and diagram-based problems like those often set in IQ tests.

I experienced a regretful setback when I was taking a test for admission to a junior high school. Despite months of hard work preparing for admission to Rakusei Junior/Senior High School, I struggled with one arithmetic question I simply couldn't solve. So attached to that question, I had little time to review the other questions, which resulted in many calculation mistakes. After all, my friends were admitted to Rakusei and I was the only one going to Todaiji Gakuen. Since that time, I've made it a rule to take other approaches and check my answers to math problems three to four times. The bitter experience in the junior high school entrance exam was a good lesson for me after all (*Laughter*).

About when did you make up your mind to focus on mathematics?

Toward the end of my high school second year, I was chosen as one of the twenty Japanese candidates for the International Mathematical Olympiad (IMO). This event turned out to be an opportunity for me to find fun in pure mathematics for the first time in my life. Until then, I had never met students of my age who were better at mathematics than myself, which was a tremendous stimulus.

At that time, I was left out of the final selection of six representatives to my regret. However, in the summer of my third year of high school, I had an opportunity to participate in a camp mostly for IMO representative candidates. It turned out that some of the fellow students I met there would change the course of my life. They invited me to go to the University of Tokyo to study mathematics together, so I decided to go to the university instead of the nearby Kyoto University. Then I was admitted to the university's Natural Sciences I, left for Tokyo and began living there alone.

After entering the university, I seldom attended classes. Rather I made it a rule to attend a weekly reading circle with those friends after deciding which textbooks to read. In those days, I was desperately voracious for mathematical knowledge, spending quite some time to study.

Then do you mean you devoted yourself to mathematics during your undergraduate years?

Not at all times. Besides studying mathematics, at the invitation by one of the reading circle friends, I took up a part time job as a math lecturer at a cram school, teaching university-class mathematics to junior and senior high school students. I was actively involved in the cram school, drawing up original curricula and creating textbooks of our own, for example. The experiences I gained at the time seem to have paved the way for what I'm doing now – teaching students.

I was also a member of an inter-college mountaineering circle, mingling with students from other universities. In a typical itinerary of three nights and four days, we climbed 3000-meter-class mountains such as those in the Southern Japan Alps, carrying a tent of our own. Some of the circle members were from Keio University. I made a friend of Mr. Kenichi Tanaka from Keio (now Associate Professor, Keio University Department of Administration Engineering) in the circle activity. Just as with the case of Dr. Tanaka, I met my future wife through this circle.

You skipped a grade when you were an undergraduate, didn't you?

Yes. Again at the invitation of those friends, I challenged the grade-skipping exam, an opportunity allowed only for juniors. All of us passed the exam, so we quit the undergraduate course halfway in the third year and advanced to the master's course. While two of my friends chose the number theory, I joined the lab of Professor Yasuyuki Kawahigashi who specialize in the operator algebras theory.

At the Kawahigashi lab, we were required to speak without looking at notebooks. At my own lab, we are following suit with

this style of learning. It was a tough practice in the beginning, but I soon found that it is a superb method to accurately understand the problem and nurture the ability to restructure the problem – far from compelling us to memorize things. Not limited to mathematics, training yourself in this way will be surely useful even after you go out into the world.

In the second year of my master's course, I studied abroad at the Mathematical Sciences Research Institute (MSRI) near the University of California, Berkeley for a little less than a year.

Returning to Japan, I completed two years of doctoral course before getting married. Then I continued research activity at the Graduate School of Mathematical Sciences, the University of Tokyo in the capacity of a postdoctoral fellow (PD) of the Japan Society for the Promotion of Science (JSPS). During this period, I also experienced an extended stay in Oregon, U.S.A. Then, I had an opportunity to spend three enjoyable years of research at the Hokkaido University Graduate School of Science (Faculty of Science) as Superlative Postdoctoral Fellow (SPD) of JSPS. Those three years were fruitful as I could fly around the world and cultivate valuable human relationships, which became the foundation supporting my current research activities.

There is one more thing I gained during the years at the Hokkaido University. Inspired by the *manga* "Hikaru-no-*Go*," I was awakened to the fun game of "*Go*". Currently, I'm a third grade rank holder of *Go*.

While mathematicians today are in great demand by businesses, it is said finding employment is difficult for mathematics researchers

Because securing a post as a mathematics researcher is highly competitive, one needs good timing and luck in addition to ability. When I completed the doctoral course, an increasing number of young people wanted to become researchers but the number of posts available was on the decrease. Naturally, they were faced with keen competition. In my case, following the service with the Hokkaido University, I had to serve as a PD at the University of Tokyo for half a year then at the University of Toronto. Since I got a preliminary offer for a post from Keio just before leaving for Toronto, I put an end to my six months of stay in Toronto much earlier than the initial plan. In April 2008, I reported to Keio University Department of Mathematics, Faculty of Science and Technology as an assistant professor. Because I was able to find employment with such a highly reputable university as Keio, I feel the five years of my PD period were not useless after all.

A good thing about Keio University Faculty of Science and Technology lies in that the relation between teachers and students is close, reflecting the Keio policy of "Half Learning, Half Teaching." Unlike mathematics departments of other universities (Japanese or overseas) I know, Keio's Department of Mathematics not only pursues pure theories of mathematics but also emphasizes application aspects of this study. Of our students, only a few become mathematics researchers after graduation. Their future courses are diverse, some becoming school teachers and others finding employment with businesses and so on. At Keio, interactions among teachers from various departments, such as labs specializing in statistics and computer sciences, are also active. Speaking of myself, I feel my field of vision has expanded considerably thanks to such an open culture.

Do you sometimes engage in joint researches yourself?

Yes. I studied alone in the beginning. But while I was in Toronto, a set theory specialist, who had read my paper, visited my office and offered a joint research on a certain problem. It was a difficult problem left unsolved for 30 to 40 years. By joining forces, however, we could solve that problem. Since that time, I'm willing to call out to other researchers when I feel joint research approach would be better.

On what occasions do you usually get inspiration?

When trying to solve problems, the first thing I do is find out things in common in several instances and phenomena and then arrange them in writing. Thinking it over for some time, there may come a moment of inspiration while I'm relaxing. Or it may come while I'm taking a shower, or walking. Such moments vary according to the situation. One day I suddenly got an inspiration. So excited with joy, I phoned up my co-researcher in spite of myself.

This is why the existence of my family, with whom I can relax in comfort, is so important. I have a family of four: my wife who is my good supporter, the first son who is an elementary school third grader, and the second son who is a preschool senior class student. The first son is already a third grade rank holder in the game of Go, the same level as me. He defeats me at times (*Laughter*). He was even chosen as a Go representative for Kanagawa Prefecture. The second son loves playing board games just like myself and is getting stronger and stronger. I'm proud of him and looking forward to his future.

◎ Some words from students ...◎

● I joined the Katsura lab simply because Dr. Katsura's class lectures were overwhelmingly interesting, where I could image even difficult problems in an understandable way. It's a tough requirement that we shouldn't look at notebooks when speaking in seminars. But this rule helps me a lot in understanding things accurately and speaking logically in public.

(Reporter & text writer : Madoka Tainaka)

For the full text of this interview
http://www.st.keio.ac.jp/kyurizukai

To get close to the truth, we need to repeat seemingly endless calculations and thought experiments. But once we have reached it, we will find it extremely simple and exquisite. I'd like my students to meet many exquisite truths from now on.

Takeshi Katsura

Born in Kyoto, Dr. Takeshi Katsura specializes in the C^*-algebras, a field of the operator algebra theory. In particular, he focuses on C^*-algebras related to dynamical systems and the set theory. In 2003, he completed the doctoral course at the Graduate School of Mathematical Sciences, the University of Tokyo. Doctor of Mathematical Sciences. After serving as a postdoctoral fellow at the Hokkaido University, University of Tokyo and University of Toronto, Dr. Katsura assumed a spost as an assistant professor of Keio University Faculty of Science and Technology in April 2008, then assumed the current post as an associate professor in April 2012.

Takeshi Katsura's ON and OFF time

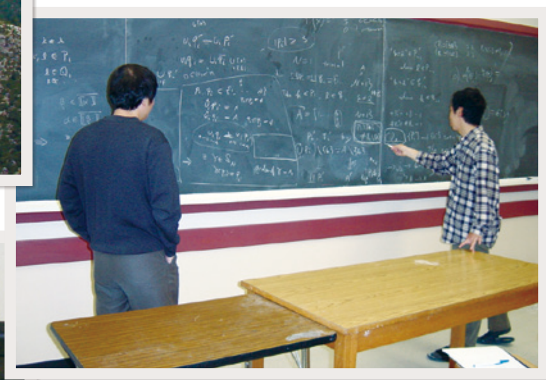
Here, let me introduce to you some of the shots showing me in ON and OFF times from my childhood through to the present.

This family photo was taken in my home in Kyoto when I was a little child before enrollment in a kindergarten. The boy standing in front of father is me and the one sitting on mother's knees is my brother two years younger than me.

This is a photo of my class taken immediately after my entrance into the University of Tokyo. The person standing next to me on the left is Mr. Kei Kobayashi who recently joined Keio University Department of Mathematics as associate professor. We met again for the first time in 20 years.

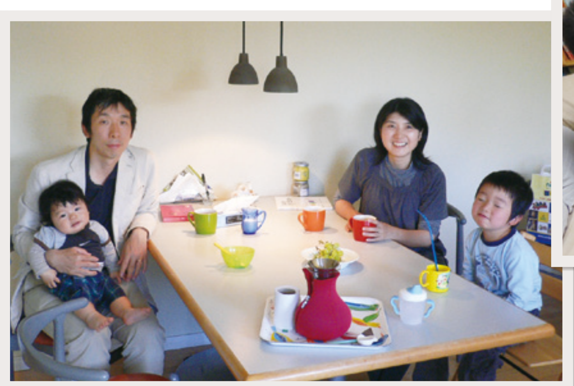
During my college days, I joined a mountaineering/skiing circle and had opportunities to mingle with friends from various universities and from disciplines other than mathematics. Dr. Kenichi Tanaka, Associate Professor of Keio University Department of Administrative Engineering, was my circle mate of the same period. He has been one of my good friends since the university freshman days.

I stayed in the United States from the second year of my master's course to the first year of doctoral course. Toward the end of that stay, Professor Kawahigashi (our advising teacher), two of my senior students and myself together visited Yosemite National Park. This photo was taken on that occasion.



From the second year of my doctoral course to the early postdoctoral period, I stayed in the University of Oregon for research. This photo shows me discussing in front of a blackboard with a Chinese teacher of the university who took good care of me.

This photo shows me being awarded with the Takebe Katahiro Prize at the Mathematical Society of Japan's Autumn Meeting 2006 held in Osaka City University. I felt very happy and honored especially because awards of this kind are much less in the field of mathematics than in the other fields of science and technology. I still remember I walked up to the stage, under tension and wearing a suit I was unused to.



After assuming a post with Keio University, I was given an opportunity to engage in research in the University of Copenhagen for one and a half years. This photo was taken in the summer of 2011 in my apartment in the suburbs of Copenhagen. My first son (four years old then) was attending a local kindergarten and the second son (nine months old then) was born in Denmark. I'm truly grateful to my wife who came with me to Denmark during pregnancy and took good care of our sons in the foreign country.

Taken in a *Go* game school that my first son (age nine) and myself attend, this shot is a scene of a match between a son and his father. Crazy about *Go*, my son is making amazingly good progress, which pleases me.

私の本棚

My favorite books

Operator Algebras

I met the author Blackadar several times while I was staying in the United States. At the time I advertised my recent research result (not much of an achievement) and later he kindly quoted just some of it in this book. Even so, I was happy to find my research result appearing in a book.

Complex Analysis

I read this book on complex analysis as a freshman in a voluntary seminar formed by several students, who would explain the contents taking turns. As it was the first book I read in English, I had double difficulties at first – the difficulty of English and that of mathematics. But I got used to both in due course. At first I had a hard time catching up with the progress due to my shallow understanding, but I gradually came to find the beauty of theories as my understanding deepened.

Number Theory for Beginners

I read this book as a high school third grader in a mathematics summer camp for junior and senior high school students. Several students took turns to explain the contents of the book. It was the first book I read on contemporary (or modern?) mathematics, which outlines relations between basic integer problems and the abstract mathematics so that even high school students can understand (if they try hard). I could feel the beauty of mathematics in this book.

C*-Algebras and W*-Algebras

I read this book on operator algebras as a master's course student during a seminar under Professor Kawahigashi. If there were other students interested in this subject, we would read it and make a presentation taking turns. But I was the only one, so I had to make a presentation alone week after week. Whenever I came across difficult points that I couldn't figure out by myself, I went to the desk of Professor Kawahigashi to ask questions. He gave me explanations very attentively.

Hikaru-no-*Go*

I read this manga while I was living in Sapporo as a postdoctoral fellow following completion of my doctoral course. This manga initiated me into the *Go* game. After learning the rules, I had enjoyed the game in my own way – slowly and steadily. But since several years ago, *Go* has become the number one pastime for both my first son and myself.

Introduction to Lebesgue Integral

This book is one I read as a sophomore in a voluntary seminar formed by several students who would explain the contents taking turns. Not only did this book make me feel the beauty of mathematics but the strictness of mathematics. This experience led me to think that the learning of analysis would suit me better rather than geometry or algebra. Looking back now, it seems to be that my judgment then was half right and half wrong.

Functional Analysis

This book is about functional analysis. I read it by myself when I was a junior. It was the first mathematics book that I chose according to my own interest. It was so difficult that I gave up halfway, but the fact that I read it by myself even halfway was meaningful to me in terms of both knowledge and experience. This book is memorable as it motivated me to specialize in operator algebras later.

Enjoying games, sports, arts and learning

Takeshi Katsura

I'm immersed in the *Go* game recently. Formerly I enjoyed *Go* games only on TV, but I took up the game of *Go* myself, taking the opportunity of my first son who began to play it. On the other hand, soccer has become a spectator sport for me although I liked playing it before. Games, sports and arts (my weak point!) seem to have many aspects in common with learning (particularly, my favorite mathematics).

While elementary schools teach sports and arts in addition to arithmetic and other studies, very few teach games like *Go*. Games are a valuable experience in that players face each other, plan a strategy of their own and make decisions at unknown phases – in repetition of these processes. As such, I think everyone should try their hand at games just like sports even though they are not taught in schools. As one proceeds to junior high and senior high school, hours for sports and arts tend to decrease as hours for the so-called "studies" increase.

Except for colleges specializing in sports or arts, most universities somehow use the so-called "scholarly subjects" only to screen successful applicants from entrance test takers. Of these subjects, mathematics is often used as a major sieve for the academic reason: ease of creating problems for which there is only one answer. But you must remember that any kind of studies, not limited to mathematics, exist not for the purpose of merely serving as sieves.

In my opinion, one of the main reasons behind the development of learning is to satisfy our intellectual curiosity. In this context, I feel that this important aspect of learning has not been emphasized in the process of learning at school.

I don't think there are those who cite the mere acquisition of knowledge as a reason for enjoying games, sports and arts. On the other hand, I believe engaging in these pursuits will bring about good results: not only the enhancement of skills in the respective areas but also the development of creative power, a wider field of vision and communication abilities that cannot be measured by numerical values. It is true that enjoying them does not require special knowledge or experience up to a certain level, but it becomes necessary to acquire knowledge and repeat practices beyond that level.

Such a process itself may not be a pleasant one, but you will be able to bear up against the process only if you think it an unavoidable step to aim high. In fact, the more enjoyment of appreciating these pursuits, the higher the levels you attain. This also holds good for learning, I think.

I think the period of entering university and several years that follow is very important for most students to decide on their future courses to take. At that time, you should free yourself from the imposed idea of dividing fields of learning into mathematics, sciences, social studies, Japanese language, foreign languages and so on. Instead, you should have a broad perspective and consider games, sports and arts as something equal to or inseparable from studies.

I'd also like to advise that when you have to decide on which course to take, you should consider the problem not only from the viewpoints of "What am I good at?" and "Which way appears easy?" but also from the viewpoints of "What is my liking?" and "Which way will be more enjoyable?"

"Will this way be useful for something?" – think about this kind of question later. Rather, you should choose whatever fields you think will be pleasant, convey the fun of your favorite pursuits to others and enjoy your own life. This is my advice.

Science and Technology **Information**

Keio University Faculty and Graduate School of Science and Technology Website

The Keio University Faculty and Graduate School of Science and Technology website introduces our education and research contents in a variety of easy-to-understand ways. For any specific research content that interests you, please click the banner concerned.

"Jukuin Orai" (Alumni Report)

In this column, "Jukuin" or Keio alumni, who are active as members of society, introduce their current activities as well as experiences during their college days.

"Gakumon-no-Susume" (Encouragement of Learning): Science

In this column, our teachers explain their own highly specialized research contents in an easy-to-understand way.

Introduction to Keio University Faculty of Science and Technology

To view, an e-book is available, on either PC or smartphone.

Video introducing Keio University Faculty of Science and Technology

This video offers an outline of our faculty, introducing its system, how students are learning in their respective departments, etc.

YouTube Keio University Channel

This channel is for video streaming of our labs' activities and research results.

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Editor's postscript

I came to realize that mathematics has depth and beauty as a research object, in addition to aspects as a field of practical learning. We are now in an era when economic objectives are often prioritized. However, I'd like to see our society look more seriously to encouraging research endeavors into the basics of science. I saw a seminar at Dr. Katsura's lab going on in an at-home atmosphere and in the uniquely Keio style called "Hangaku-hankyo"(Learning while Teaching, Teaching while Learning) – a tradition allowing the student to stand on the platform for a presentation. I have realized anew that learning is not simply for acquiring knowledge.

(Kenji Kobayashi)

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