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Contents

Article

Mathematics in Industry

A technological challenge and an opportunity for mathematicians

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Although the role of Mathematical Sciences in Civilization has been of central importance for centuries, the current trend to a global economy and a knowledge society has placed information and innovation technologies increasingly dependent on scientific research, which results and techniques are underpinned and driven by Mathematics.

Recognizing that Mathematics provides the context for communication and discovery in many other disciplines, the Global Science Forum (GSF) of the Organization for Economic Co-operation and Development (OECD) has promoted a report on "Mathematics and Industry", which was published in July 2008 and is openly accessible at the site: http://www.oecd.org/dataoecd/47/1/41019441.pdf.

This report is a consequence of an OECD workshop, held in Heidelberg under German initiative and the coordination of Willi Jäger, on March 22-24, 2007. That meeting had the participation of more than fifty experts from industry, academia, and government agencies, from fourteen European countries, Japan, Australia, Canada, USA and Russia. Companies like Airbus, Nokia, the Norwegian Statoil, the Nipon Steel Corporation, the Italian STMicroelectronics, the German BASF AG, Bayer and HEIDELBERG Print Media Industry where among the industries that have send participants from their research departments.

Mathematics (or the mathematical sciences, including statistics and computing) is considered in its broadest sense, as well as Industry, is interpreted "as any activity of economic or social value, including the service industry, regardless of whether it is in the public or private sector". The analysis of their current relationship, including significant trends in mathematical research in academia and industrial challenges that may create opportunities for interactions and partnership between both sides, as well as the formulation of recommendations was the aim of that workshop.

The report is addressed to the community of mathematical scientists, to the industry (large, medium and small size) and governments and it recommends the improvement of the infrastructure for increased interactions, both in academia and industry, the enhancement of the curriculum for students of mathematics and the reinforcement of coordination and cooperation at national and international levels.

Mathematics versus Industry

While Mathematics, as a scientific discipline, has seen an enormous development, mathematicians, that tend to classify themselves either "pure" or "applied", not often look at its applications to industrial problems. Academia structure, with known obstacles to the interdisciplinarity and cross-disciplinarity, as well as current cultural practices are facing new challenges and transformations.

Overcoming the traditional classification between "pure mathematicians", that exclusively dedicate to inquiry new concepts, new theorems and new theories within the discipline, and "applied mathematicians" that limit themselves to the use of known techniques to address problems outside the discipline, more than ever the future of Mathematics depends in a critical way on a strong connection and interaction between the creators and the users of this discipline.

Without loosing their freedom in academic research, "mathematics and mathematicians must recognize the importance of industrial problems for the development of their discipline and should adjust the academic curriculum to the new environment". Problems from Chemical and Pharmaceutics Industry, Oil Exploration, Medical Imaging and Biotechnology, Microelectronics and Nanotechnology, Logistics and Finance, Information Security and Communications or Entertainment, are good examples that can nourish new and exciting progress in the mathematical sciences.

The following mathematical areas are basic for the applications: dynamical systems (asymptotics, stability, time-space patterns,...); multi-scale analysis, transitions between models in different scales; systems reduction, algorithms for high dimensional problems; flow, transport and reactions on the micro-scale level; multi-physics problems, reactive laminar and turbulent flow, diffusion and transport; analytical and numerical treatment of processes in random media; inverse modelling and parameter identification;. continuous and discrete optimization, shape optimization; design of experiments and control of technological processes; multidimensional image processing, model based image analysis, visualization; advanced statistical methods for data processing.

On the other hand, Mathematics is a key and enabling technology for the industry, as it "provides a logically coherent framework and a universal language for the analysis, optimization, and control of industrial processes", even if its contributions are, in most cases, invisible in the industrial products. While industry is facing tremendous local and global challenges, innovative companies that are able to exploit properly that enabling technology can rapidly gain a clear advantage over their competitors.

The OECD reports highlights a paragraph from an article published in February 2006 in the newspaper Financial Times on "Mathematics offers business a formula for success": [Mathematicians] have come up with an impressive multiplication formula for British commerce and industry: spend a few million pounds promoting the use of maths as a strategic tool, and add billions of pounds of value to businesses. That is the thinking about a new government-industry consortium, the Mathematics Knowledge Transfer Network. The network aims to boost the use of maths throughout the economy from grocery distribution to banking, telecoms to manufacturing.

Mathematics as a partner to the Industry

Recognizing that "the interface between mathematics and industry is much more than a medium for technology transfer", the Report supports the vision of a synergetic partnership between mathematics and industry where information is exchanged freely at the precompetitive stage, and knowledge is shared profitably by the mathematical and industrial communities.

Referring to existing examples of mechanisms of partnership, like Interdisciplinary Research Centres, faculty positions for industrial mathematics, research internships, special interest groups sponsored by professional societies or government agencies, Study Groups and direct research collaborations, students activities, "technology translation" agents, consultancy and transnational cooperation, diverse experiences and large differences have been recognized among the OECD countries, according to their state of development and economic structure.

An important issue raised at the OECD report is the intellectual property one, since it is a delicate issue and may present difficulties. Clearly mathematics is not a tangible product, and mathematical equations, with their expression in algorithmic form cannot be patented. However, when mathematical algorithms are implemented in computer software, intellectual properties rights issues may arise and are fraught with difficulties, as the Report observes. But since these practices and processes "vary greatly according to country, industry, and even academic institution, the workshop participants refrained from making any specific recommendations about the management of intellectual property, except to point to the need to share best practices in the management of mathematical intellectual property and to learn from successes and failures of scientists and organizations working at the interface of mathematics and industry".

Among the conclusions and recommendations to stimulate the interaction of Mathematics and Industrial Innovation, it is important to refer the need of Interdisciplinary Research Centres, special positions of Industrial Mathematics, Workshops, specific actions in Education and Training, the creation of initiatives at their interface (joint teams, translators, networks of experts, information sites, etc.), as well as national and international collaboration and coordination.

The European Mathematical Society response

The European mathematical community has a relevant experience and non negligible cooperation record in industrial mathematics. For instance, the 6th International Congress on Industrial and Applied Mathematics was held in July 2007 in Zurich and was the fourth organized in Europe. It hosted, in particular, a Panel Discussion on the OECD Global Science Forum report, where the recommendations to improve the transfer of mathematics to industry were presented and where the requirement of the education of students to be more interdisciplinary was debated.

In order to promote the interaction between universities and research groups in industry, since 1986, the European Consortium for Mathematics in Industry (ECMI) established a network of expertise, nowadays with about twenty academic members. ECMI organizes a regular series of conferences and common activities, including a joint educational programme on Mathematics for Industry operating on a European scale.

The European Mathematical Society (EMS), through its Applied Mathematics Committee chaired by Mario Primicerio (`http://ems.math.uni-bremen.de/comm-applied.html`), has proposed to the European Science Foundation (ESF) the creation of a pilot project directed towards the enhancement of the European mathematics/industry interface. The aim of the project is twofold: on one side, to focus on "in house" industrial mathematics, i.e. on mathematicians working in industry and services; to gather information on their educational curricula, their recruitment and the possible need of continuing education, in particular, to question if the professional career of "technomathematician" does (or should) exist; on the other hand, to consider the cooperation between academic research and industry, to analyse the different forms of partnership between university and research centres on one side and industry and services on the other; and to stimulate a coordinate program of research.

The ESF has expressed a preliminary agreement to finance a Forward Look project "Maths & Industry" and has sponsored a "Scoping workshop" aimed to define its topics, the timetable and the prospected outputs of the project. The workshop took place in Pisa, Italia, on 20-21 December 2008, and was hosted by the Centro De Giorgi. With nineteen participants from ten European countries, the meeting contributed to the elaboration of the project that aims an ESF Forward Look Report, with three directions: academia-industry interface; training and careers and opportunities and challenges.

The activities that ESF may promote will take place during 2009 and 2010, and they should produce the state-of-the-art revue in the area, highlighting of the major advances in the last years, present the scientific challenges, including the identification of European strength and weakness, and present a vision with major goals that could provide directions for research in the medium and long term time frame and contribute to the implementation plan (in terms of infrastructure, institutional innovation, human resources, governance).

This is a timely and very important project. The situation differs from one European country to another and this should be properly taken into account. Such an initiative should enhance the European cooperation and activity in the area of mathematics in industry, in particular through a series of special Workshops. The European Mathematical Society, through its permanent special committee on Applied Mathematics, is the natural candidate to act as the reference institution for the project and the ERCOM centres the natural hosts of "Maths & Industry" events in Europe.

Coming Events

April, 17-19, 2009: 1st Porto Meeting on Mathematics for Industry,

Department of Mathematics, University of Porto.

Organizers

Pedro Freitas (UTL/GFM).

Diogo Pinheiro (CEMAPRE/CMUP).

Carla Pinto (ISEP/CMUP).

João Nuno Tavares (CMUP).

José Miguel Urbano (CMUC).

Aims

The purpose of this meeting is to focus the attention on the many and varied opportunities to promote applications of mathematics to industrial problems. Its major objectives are:

- Development and encouragement of industrial and academic collaboration, facilitating contacts between academic, industrial, business and finance users of mathematics.
- Through "bridging the industrial/academic barrier" these meetings will provide opportunities to present successful collaborations and to elaborate elements such as technology transfer, differing vocabularies and goals, nurturing of contacts and resolution of issues.
- To attract undergraduate students to distinctive and relevant formation profiles, motivate them during their study, and advance their personal training in Mathematics and its Applications to Industry, Finance, etc.

The meeting will be focused on short courses, of three one-hour lectures each, given by invited distinguished researchers, which are supplemented by contributed short talks by other participants and posters of case studies.

Main Speakers and minicourses

Agostinho Agra (University of Aveiro, Portugal)
Discrete models applied to real industrial problems.

Alfredo Bermudez de Castro (University of Santiago de Compostela, Spain)
(*Title to be announced*).

Enrique ZuaZua Iriondo (Basque Center for Applied Mathematics, Bilbao, Spain)
Flow control in the presence of shocks: theory, numerics and applications.

Stanley R. Pliska (Department of Finance, University of Illinois at Chicago, USA)
Mathematical Methods for Portfolio Management.

For more information about the event, see

`http://www.fc.up.pt/cmup/mathindustry/`

April, 20-24, 2009: The 69th European Study Group with Industry 2009,

Department of Mathematics, University of Coimbra.

Organizers

Adérito Araújo (LCM/CMUC).

Carlota Simões (DMUC).

João Nuno Tavares (CMUP).

José Miguel Urbano (CMUC).

Pedro Freitas (FMH/UTL and GFM-UL).

Aims

The purpose of these meetings is to strengthen the links between Mathematics and Industry by using Mathematics to tackle industrial problems which are proposed by industrial partners.

This meeting is part of the series of European Study Groups and will count with the participation of several European experts with a large experience in this type of events.

More information on study groups and related aspects is available at the International Study Groups website (http://www.maths-in-industry.org), the Smith Institute (http://www.smithinst.ac.uk) and the European Consortium for Mathematics in Industry (http://www.ecmi-indmath.org/info/events.php).

For more information about the event, see

`http://www.mat.uc.pt/esgi69`

July, 2009: Kinetics and statistical methods for complex particle systems,

Complexo Interdisciplinar da Universidade de Lisboa

An initiative of the UTAustin-Portugal program in Mathematics in co-operation with CIM.

Summer school: July 13-18, 2009

Workshop: July 20-24, 2009.

Organizers

Irene Gamba (University of Austin).

M. C. Carvalho (University of Lisbon).

Rui Vilela Mendes (University of Lisbon).

Diogo Gomes (Technical University of Lisbon).

Fabio Chalub (New University of Lisbon).

Aims

This two weeks event will consist of a summer school of 5 lectures of 4-hour mini courses during the first week, and a follow up with a second week holding a conference featuring talks at a more advanced level. The initiative will focus on analytical and numerical issues related to dynamical properties associated to non conservative interactive particle systems where non-equilibrium statistical asymptotic states are a signature of their complexity. This area of research have been emerging in the last decade as a follow up of recent studies to kinetic systems that models the evolutions of probabilities distributions into non-classical states where classical macroscopic models fail. New simulations that incorporate stochasticity, multi-scale and approximations to nontrivial diffusion limits will be addressed. The meetings will discuss connections to probability and stochastic theory in connection to natural and social sciences. Examples of such systems have been recently studied and reported in the statistical modeling of rapid granular flows, coalescence-breakage models for jet-bubble flows, mixtures under chemical reactions, as well as in social science areas such as modeling systems of particles swarms in species social behavior, traffic networks (such as vehicular traffic on highways, TCP traffic on internet, traffic of goods on supply chains), and economics models related information sharing in large populations, as well as applications to climate modeling via stochastic methods.

Summer school lecturers

Eric Carlen (Rutgers University, USA).

Pierre Degond, (University P. Sabatier, Toulouse, France).

Irene M. Gamba (University of Texas, Austin, USA).

Markos Katsoulakis (University of Massachusetts, Amherst, USA)

Robert Pego (Carnegie Mellon University, USA).

October 1-4, 2009: Didactics of Mathematics as a Mathematical Discipline (a XXIst century Felix Klein's follow up),

University of Madeira, Funchal.

Organizing Committee

Elfrida Ralha (University of Minho).

Jaime Carvalho e Silva (University of Coimbra).

Suzana Nápoles (University of Lisbon).

José Manuel Castanheira (University of Madeira).

Local Organizers

Elsa Fernandes (University of Madeira).

Sandra Mendonça (University of Madeira).

Aims

A century ago Felix Klein's lectures on mathematics for secondary teachers were first published: "Elementarmathematik vom höheren Standpunkte aus" (1908). This comprehensive view challenged both teachers and mathematicians to consider the relationship between mathematics as a school subject, and mathematics as a scientific discipline. As Klein wrote: "we first raise the question as to how these things are handled in the schools; then we shall proceed to the question as to what they imply when viewed from an advanced standpoint." To this we must add "another point in this instruction which is usually neglected in university teaching. It is the application of numbers to practical life."

This last 100 years have witnessed many changes in mathematics that provoked major changes and challenges for school mathematics. The role of mathematics in the education of scientists, economists and engineers seems to have achieved unprecedented societal unanimity. While Klein's writing remains a valuable source insight, it seems timely to revisit this theme by linking the topics and approaches of upper secondary with the field of mathematics. This is an important challenge for Mathematics Education.

Can we analyse the new challenges for mathematics in the XXIst century? Can we devise a XXIst century book that will be "read with pleasure and profit alike by the scholar, the student, and the teacher" (AMS Book Reviews 1940) taking into account all the dimensions Klein stressed: intuitive, genetic, applications?

This workshop aims at discussing this subject, contemplating the following strands:

a) Which special characteristics can be found in mathematics as a school subject for the XXIst century?

b) Which kind of relationships between mathematics as a school subject and mathematics as a scientific discipline must be developed/implemented?

c) Which challenges are national and which are international? Which are individual and which are societal?

d) Which new mathematics should be included (apart from arithmetic, algebra, analysis and geometry), why and from which "advanced standpoint"?

e) What should be the methodology of such a book in order to be read by "the scholar, the student, and the teacher"?

f) Which forms should this book have? Paper, multimedia, web-updated encyclopædia. Are these forms changing content structure?

g) How to integrate "elementary" recent applications in such a book?

For updated information on these events, see

http://www.cim.pt/?q=events

Article

European Study Groups with Industry in Portugal: importing a forty year old concept

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What do tyre recycling, the incubation of penguin eggs, LEGO and traffic monitoring have in common? If your answer includes any complicated multidisciplinary theory involving female penguins going down the Antarctic highway on LEGO vehicles with recycled tyres, you are way off the mark. These and other disparate problems such as consumers' behaviour, artificial heart pumps, flight simulators and a host of other seemingly unrelated problems are brought together by the fact that they have all been presented by industrial partners at European Study Groups with Industry (ESGI) in Denmark, the Netherlands, Portugal and the UK, within the last few years. In short, mathematics is the common denominator.

ESGIs originated in the UK in 1968 under the name Oxford Study Groups with Industry. The concept has, since then, been adopted by other countries such as those mentioned above, and study groups have become a well established institution and the leading workshop for interaction between mathematics and industry in Europe. Besides being a source for interesting new problems in mathematics, they also function as a privileged ground for the transfer of mathematical technology between the academic world and industry.

How does it work?

Study groups normally take up the best part of a week, starting on Monday morning with the presentation of the problems by industry and finishing on Thursday or Friday morning with the presentation of the results obtained in the meantime by the mathematicians involved. In between, a lot of brainstorming, modelling, experimenting and discussion goes on, from early in the morning till well after dinner everyday. Not to mention, of course, the usage of a wide range of mathematical techniques.

A typical study group will address between three to six problems, each being presented by a participant from industry appointed by the firm submitting the problem. The presentation will consist of a brief summary of the area of expertise of this particular sector of the company, and a full description of the problem, including solutions already attempted. The precise aim to be achieved should be specified as clearly as possible, together with all the relevant information available. A short written summary of the problem should have been sent to the organizers beforehand, so that there is enough time to contact experts in specific areas if necessary. Since it is not realistic to establish a confidentiality agreement, any sensitive data should not be given explicitly at this stage. However, if sensitive information is involved, firms should provide mock data to be used during the meeting. Written reports produced by some of the participants are sent to firms later on.

What can companies expect from a study group, and why should they participate?

Study groups are exploratory meetings. Except in very specific cases, it is too optimistic to expect a finished, ready to use and well wrapped up solution to result from a four or five day meeting. This will be particularly true when what is at stake is not a specific problem but how to start developing a project to achieve a certain goal, when the production of software is necessary to implement an algorithm, or sometimes even just because for technical reasons it is not physically possible to finish the work in the available time. As an illustration of this last situation take one of the problems presented by Biosafe at the 65$^{\text{th}}$ ESGI in Porto in 2008. This required numerical simulations of Navier-Stokes equations which would, by themselves and with the means available, take more time to run than the duration of the meeting itself. However, these simulations could be carried out after the meeting and the results were included in the report sent to the firm afterwards.

In any case, enough information is available by the end of a study group for a company to decide whether this is enough and the company itself may pick up from here, or whether it will find it advantageous to establish a more lasting association with one or several mathematicians to pursue a particular goal.

An important point that should be stressed here is that in general most firms, particularly smaller ones, do not have neither the means nor the need to keep the necessary human resources to address specific problems which may arise. In this sense, study groups may be seen as a possibility for small and medium sized firms to have access to specialized know-how that they will otherwise lack.

What can mathematicians expect from a study group, and why should they participate?

The mathematics needed for problems arising in study groups varies a lot in type, depth, difficulty and novelty. It is, for instance, possible that once a problem has been translated into mathematical form the mathematics needed to solve the problem are trivial. However, this is normally not the case, and industrial problems have become more and more a source of challenging new situations which bring together many aspects of what are traditionally called pure and applied mathematics. In some areas such as statistics, this may also allow access to relevant data for testing methods and algorithms which would otherwise be difficult to come by.

Another important issue is that being in contact with industrial problems keeps mathematicians updated on the challenges facing engineers and other professionals who receive part of their university training in mathematics. If nothing else, this provides a wide range of fresh examples that can be used to motivate many of the fundamental concepts which are taught in first and second year linear algebra and calculus courses. Showing how checking the fuel level in an airplane tank gives rise to a natural example of a continuous, non differentiable, function, does not jeopardize mathematical rigour while at the same time it allows teachers to emphasize the fact that such objects do exist. Not to mention the fact that it is not obvious how to describe and deal with such functions in practical terms, the actual problem which was posed by Airbus at the 56$^{\text{th}}$ ESGI in Bath, 2005. The report on this problem, together with a fairly comprehensive collection of ESGI reports, are available at the Study Groups web site [10].

Study groups in Portugal

The first study group to be hosted in Portugal was the 60$^{\text{th}}$ in the ESGI series [1]. It came about as a result of the chance encounter of several people at the meeting of the Portuguese Mathematical Society that took place at the Instituto Superior de Engenharia de Lisboa (ISEL) in 2006. The study group itself took place approximately one year later, also at ISEL, and counted with the collaboration of several British specialists including John Ockendon FRS, the Research Director of the Oxford Centre for Industrial and Applied Mathematics [9] and one of the mathematicians with more study groups experience. Two problems were presented, one on traffic flow monitoring (BRISA) and another on a Stewart platform simulator (FunZone Villages). The former provided an example where the firm has a project in mind which they want to embark on (in this case, providing customer information on the A5 motorway connecting Lisbon to Cascais), and wants to know how they should go about merging all the data available, which models to use, etc.

The second problem provided a classical example of a specific situation where there is already a working model in place, but where things are not functioning as expected. Understanding the problem and proposing solutions required techniques from algebra, analysis and geometry.

The 65$^{\text{th}}$ ESGI took place in Porto in April 2008 [2] and had four problems, proposed by three firms:

Biosafe (cooling of a rotor and material separation in tyre recycling);

Forever (task assignment in a factory);

GROHE (warehouse logistics).

Except for the second of Biosafe's problems which was similar in nature to that of BRISA mentioned above in the sense that Biosafe wanted some input before embarking on a project, all other problems fell into the category of specific situations. They involved techniques from partial differential equations and numerical analysis (the first of Biosafe's problems) and combinatorial optimization (GROHE and Forever problems).

After the Porto meeting, the three participating companies were asked to comment upon different aspects of the process. In general, they all agreed that the meeting had been fruitful and at least for two of the problems the results provided were going to be used by the firms.

The 69$^{\text{th}}$ ESGI will take place in Coimbra between the 20$^{\text{th}}$ and the 24$^{\text{th}}$ of April 2009 [3], and will be preceded by a three day workshop in Porto (April 16$^{\text{th}}$ – 18$^{\text{th}}$) [4].

Industrial Mathematics in Portugal: bringing it all together

Anyone who has ever participated in a study group knows that these can be great intellectual fun. However, in order for this to be a sustainable activity and have a lasting positive effect on the relation between mathematics and industry, study groups should not be seen in isolation from other academic activities. Although they are mentioned in the 2008 OECD report on Mathematics in Industry [8], study groups are just one of several possible mechanisms recommended to enable the partnership between these two forces to flourish. In fact, irrespectively of how successful study groups are point wise, it is only if coupled to other initiatives that their outcome will have a lasting positive influence on both mathematics and industry.

In particular, there should exist a structure at the national level bringing together centres and departments involved in industrial mathematics. This would then integrate the organization of study groups and other activities to be developed in parallel. Some examples of these are the following:

1. Integration of student activities: 2^{nd} cycles in Applied Mathematics at Portuguese Universities. Some of these already include a period during which the student spends some time at a firm working on a specific problem. In the future, these courses could be organized in such a way that during one week students would attend the study group, thus obtaining some important hands on experience. In the Danish study group system this type of practice already provides some ECTS count for students. Apart from putting students in contact with real world problems, study groups themselves would then also function as an aggregating factor, allowing researchers and students working in these areas to be in contact with each other and giving outside visibility to the university community working in industrial mathematics. Such a connection between a degree in mathematics and prospective employers might also help strengthen the number of students applying for these courses, at a point in time when this might become critical for the existence of sustained 2^{nd} and 3^{rd} cycles in these and related areas.
2. Invited chairs in Industrial Mathematics: It would allow for a great qualitative leap to be able to bring to this country specialists in this field taking advantage, for instance, of the Ciência 2008 program sponsored by the Foundation for Science and Technology (FCT).
3. Knowledge transfer networks: To systematically reach industrial partners who might be interested in collaborating with academia is a nontrivial task requiring a lot of time and experience. Without the existence of full-time technology translators, promoting these initiatives within industry will be very difficult. Such a system is already in place in countries like the UK [7].
4. Research institutes: At a much more ambitious level, the Portuguese mathematical community should aim at the creation of an institute similar in nature to the Oxford Centre for Industrial and Applied Mathematics [9] in the UK, or the Fraunhofer-Chalmers Research Centre in Industrial Mathematics [5] at Chalmers University in Sweden, for instance. Apart from the obvious advantages of having a successful institute of this type, it would dramatically increase the visibility of the usefulness of mathematics in today's world, not only to industry but also to the general public.

The existence of a national structure of this type would greatly benefit the Portuguese mathematical community in general and also help the development of certain aspects of industry with emphasis on small and medium sized firms as mentioned above.

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Feature Article

How Do Fish-Food Pellets Float?

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Abstract

One growth industry over recent years has been fish farming. Fish are raised in large cages kept within sea inlets, estuaries or lakes. The fish are fed with food pellets which are scattered onto the water above the cages. Ideally the pellets sink within fifteen seconds and can then be eaten by the caged fish. Sometimes there have been problems at fish farms with the fish food floating for too long, whereas in simple laboratory experiments with the same batch of pellets, throwing a handful onto water in a bucket, the pellets were observed to sink quickly. The aim is to understand why.

1 Introduction

An agricultural industry which has expanded rapidly in recent decades has been fish farming. The fish, which are being reared for food, are kept in large cages in inlets from the sea or fresh-water lakes. The fish, in turn, need to be fed and this is commonly done by scattering food pellets, each of which has a shape approximately that of a circular cylinder, onto the surface of the water above the caged fish. Ideally the pellets sink quickly – as might be expected because their density is greater than that of water, although the two densities are comparable. As the pellets sink they can be eaten by the fish. Sometimes, however, batches of pellets have been prone to prolonged floating, allowing them to drift away from the fish cages and/or be eaten by birds. In such cases the pellet manufacturers might run tests with pellets of the same batch, throwing them onto the surface of water in a bucket. The pellets in such tests might proceed to sink rapidly, even if the water used is identical (in terms of dissolved impurities and temperature) to that at the fish farm. It is important to understand the difference between the two cases, and hence to be able to conduct better tests which can more accurately represent what is done in practice – and improve the quality of the manufacturers' products.

One hypothesis has been that the surface tension of the water plays a key role. This short article is aimed at seeing how this effect can help determine whether or not an object, such as a fish-food pellet, will float on the surface of a liquid. For simplicity, and also motivated by the shape of the pellets – circular cylinders with lengths greater than their diameters – the object is imagined to be an infinitely long cylinder with circular cross-section, rather than the true, approximately cylindrical shape (with one concave and one convex end), as sketched in Fig. 1.

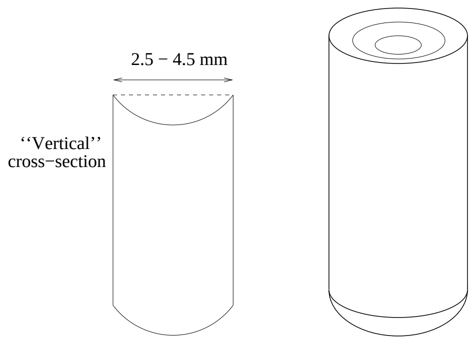

Figure 1: *Schematic diagram of a food pellet.*

It is then possible to to consider a two-dimensional situation, with a circular object floating at the surface of an infinite expanse of liquid (which would occupy a half plane if the object had not been present); see Fig. 2.

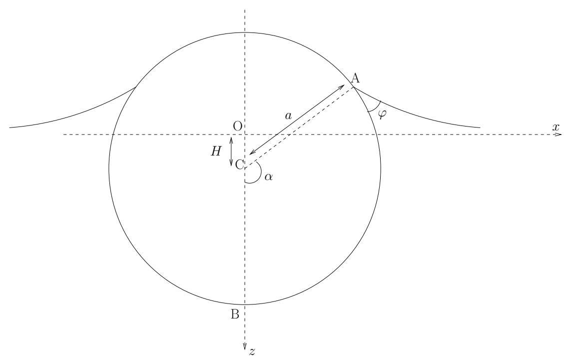

Figure 2: *The two-dimensional case (or a cross-section of a long cylindrical pellet), with a circular object of radius a. Its centre lies a distance H below the undisturbed level of the water while angle α is subtended at the centre, C, by the point on the circle vertically below, B, and the point where the water surface meets the pellet, A.*

We start by writing down the standard equations for the free surface of water, $z = h(x)$, where z is measured vertically downwards from the undisturbed water level, *i.e.* the water surface is $z = h = 0$ at $x = \pm\infty$, and x is the horizontal azis, in the plane of the pellet cross-section, measured from the centre of the circle. (This choice makes things symmetric about the z axis, $x = 0$.) Next the equilibrium conditions for a floating pellet are obtained and used to get equations relating H, the depth of the pellet centre line below the undisturbed surface (so that the circle centre is at C, $(x, z) = (0, H)$), and the points at which the water surface meets the circle. These points can be specified by the angle α between CA, with A the meeting point with $x > 0$, and the downward vertical (see Fig. 2). The **contact angle**, φ in Fig. 2 plays an important role these equations. This particular angle is between the water/air interface and pellet surface, measured through the water. The contact angle depends on the nature of the solid surface: φ will be small for "hydrophilic" materials (it is energetically favourable for the water and the pellet to be in contact) and close to π for "hydrophobic" materials (as would be the case for a waxy or oily substance). Special cases include $\varphi = \pi$, $\varphi = \pi/2$, which for convenience will be particularly looked at here, and $\varphi = 0$, which also deserves comment and corresponds to "wetting" of the pellet surface.

We shall end by considering the implications of the results for floating, and for the experiments.

2 The Model

2.1 Equations for the water surface

Throughout, for simplicity, we shall subtract off atmospheric pressure from all pressures appearing in the model. This means that at large distances the pressure p can be taken to be zero at the water surface, so $p = 0$ at $z = 0$. Because there is equilibrium, pressure is hydrostatic in the water:

$$p = \rho g z \quad \text{for} \quad z > h\,. \tag{2.1}$$

At an interface between two fluids there is a jump in pressure. Here

$$p = p_{\text{water}} - p_{\text{air}} = \sigma\kappa\,, \tag{2.2}$$

where σ is the **surface tension** between water and air and κ is the curvature of the surface, taken to be positive if the surface curves towards the water. To be precise,

$$\kappa = -\frac{\mathrm{d}\theta}{\mathrm{d}s}\,, \tag{2.3}$$

with θ = angle of slope (positive for a surface rising as x increases) and s = distance along the surface (in the $x - z$ plane), so

$$\cos\theta = \frac{\mathrm{d}x}{\mathrm{d}s}\,, \quad \tan\theta = -\frac{\mathrm{d}h}{\mathrm{d}x}\,, \quad \sin\theta = -\frac{\mathrm{d}h}{\mathrm{d}s}\,, \tag{2.4}$$

see Fig. 3.

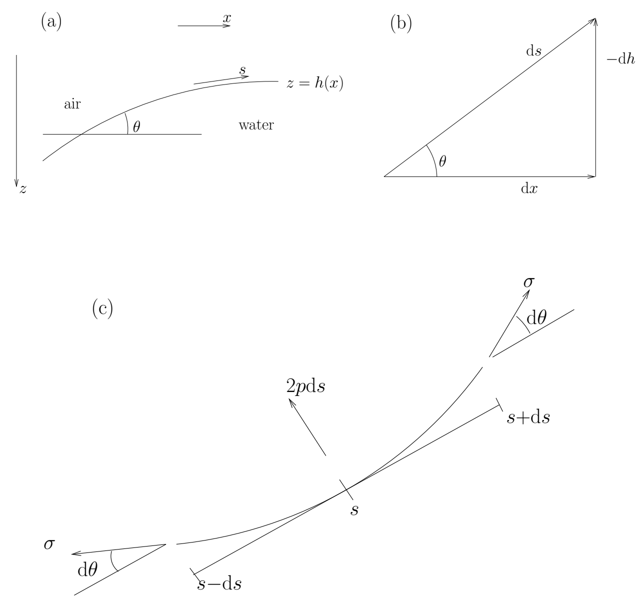

Figure 3: *(a) The water surface away from the pellet. (b) A small element of a curve along the surface in the $x - z$ plane. (c) Forces which must balance for a small section of the surface between $s - \mathrm{d}s$ and $s + \mathrm{d}s$ (shown for a case of $\kappa < 0$).*

These are standard results. Eqn. (2.2) comes from requiring that normal forces balance on a small section of the surface: force from water pressure (towards the air) is equal to

$$\text{pressure} \times \text{length} = 2p\mathrm{d}s,$$

is the same as normal force from surface tension (towards the water), namely

$$-2\sigma \sin \mathrm{d}\theta \approx -2\sigma \mathrm{d}\theta = -2\sigma \frac{\mathrm{d}\theta}{\mathrm{d}s}\mathrm{d}s = 2\sigma\kappa \mathrm{d}s,$$

since $\mathrm{d}\theta$ is small. See Fig. 3(c).

Note that it follows from (2.4) that

$$\kappa \cos\theta = \frac{\mathrm{d}^2 h}{\mathrm{d}s^2}\,. \tag{2.5}$$

Using the known hydrostatic pressure, there is then a differential equation for the depth of the water surface:

$$\begin{aligned} p \;&=\; \rho g h \;=\; -\sigma\frac{\mathrm{d}\theta}{\mathrm{d}s} \\ &=\; -\sigma\frac{\mathrm{d}\theta}{\mathrm{d}h}\frac{\mathrm{d}h}{\mathrm{d}s} \;=\; \sigma\frac{\mathrm{d}\theta}{\mathrm{d}h}\sin\theta \end{aligned} \tag{2.6}$$

or

$$h\frac{\mathrm{d}h}{\mathrm{d}\theta} = \frac{\sigma}{\rho g}\sin\theta\,. \tag{2.7}$$

The quantity $\sigma/\rho g$ has dimensions of area and we choose to write it as ℓ^2:

$$\ell = \sqrt{\sigma/\rho g} \approx 3 \text{ mm} \tag{2.8}$$

for water with normal gravity. This distance is the length scale characteristic of a water meniscus. Now

$$h\frac{\mathrm{d}h}{\mathrm{d}\theta} = \ell^2 \sin\theta\,. \tag{2.9}$$

(The problem can be made somewhat simpler by scaling. On writing $\hat{h} = h/\ell$, (2.9) becomes $\hat{h}\,\mathrm{d}\hat{h}/\mathrm{d}\theta = \sin\theta$.)

As x and s tend to infinity, $h \to 0$ and the slope θ also goes to zero. The ODE (2.9) is therefore subject to the condition

$$h = 0 \quad \text{at} \quad \theta = 0\,. \tag{2.10}$$

The solution to (2.9) and (2.10) satisfies

$$h^2 = 2\ell^2(1-\cos\theta) = 4\ell^2\sin^2\frac{\theta}{2}\,. \tag{2.11}$$

Two cases might be considered:

(1) The presence of the pellet raises the water level, so $h < 0$ and $\theta < 0$, in which case (2.11) gives $-h = -2\ell\sin(\theta/2)$.

(2) The presence of the pellet lowers the water level, so $h > 0$ and $\theta > 0$, in which case (2.11) gives $h = 2\ell\sin(\theta/2)$.

We see that in either case

$$h = 2\ell\sin\frac{\theta}{2}\,. \tag{2.12}$$

For more on surface tension and on curvature of curves and of surfaces, see, for example, the books [1], [2] and [3].

2.2 Equations for the pellet position

Referring back to Fig. 2, the depth of the pellet centre, H, pellet radius, a, angle α giving the location, A, of the intersection of the free surface with the pellet boundary, and the local depth of A, say h^*, are related through

$$h^* = H + a\cos\alpha\,. \tag{2.13}$$

Looking at, θ^*, the local angle of slope of the free surface, it is seen that

$$\theta^* = \alpha + \varphi - \pi\,, \tag{2.14}$$

with φ the contact angle. Note that $|\theta^*| > \pi/2$ corresponds to a free surface which turns over; see Fig. 4.

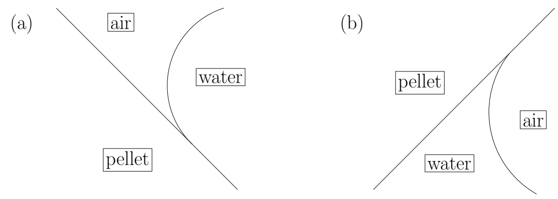

Figure 4: *A water surface which turns over. (a) The case of $h > 0$, so $\pi/2 < \theta^* < \pi$. (b) The case of $h < 0$, so $-\pi < \theta^* < -\pi/2$.*

With h^* and θ^* related through (2.12), (2.13) and (2.14) give

$$\begin{aligned} H &= 2\ell\sin\left(\frac{\alpha+\varphi-\pi}{2}\right) - a\cos\alpha \\ &= -\left(2\ell\cos\left(\frac{\alpha+\varphi}{2}\right) + a\cos\alpha\right)\,. \end{aligned} \tag{2.15}$$

A final equation relating the unknowns H and α is obtained from requiring that the total force on the pellet be zero for it to float in equilibrium. Because of symmetry it is only necessary to look at the vertical components.

The surface tension at the two sides provides an upward force of

$$2\sigma\sin\theta^* = -2\sigma\sin(\alpha+\varphi)\,.$$

There is also an upward buoyancy force from the water pressure of

$$\begin{aligned} \int_{-\alpha}^{\alpha} (p\cos\phi)(a\,\mathrm{d}\phi) &= 2\rho g a \int_0^{\alpha} (H + a\cos\phi)\cos\phi\,\mathrm{d}\phi \\ &= \rho g a\left(2H\sin\alpha + a\left(\alpha + \frac{\sin 2\alpha}{2}\right)\right), \end{aligned}$$

taking a variable of integration $\phi =$ angle from vertical from the pellet centre to a point on its surface, so that the local depth is $z = H + a\cos\phi$. These two upward forces must balance the weight of the pellet, $\rho_\mathrm{p} g\pi a^2$, with $\rho_\mathrm{p} =$ the pellet's density as πa^2 is the relevant cross-sectional area:

$$\rho_\mathrm{p} g\pi a^2 = \rho g a\left(2H\sin\alpha + a\left(\alpha + \frac{\sin 2\alpha}{2}\right)\right) - 2\sigma\sin(\alpha+\varphi). \tag{2.16}$$

Note that the right-hand side of (2.16) should, by Archimedes' principle, be the weight of water displaced, *i.e.* twice that in $0 < z < H + a\cos\phi$ for $0 < \phi < \alpha$ plus twice that in $0 < z < h(x)$ for $x > a\sin\alpha$, thinking of $0 \le \theta^* \le \pi/2$ for simplicity. It is clear that $\rho g \int_0^{a\sin\alpha}(H + a\cos\phi)\,\mathrm{d}x$ gives, on writing $x = a\sin\phi$, the first part of (2.16). The second part comes from

$$\begin{aligned}\sigma\sin\theta^* &= \int_{a\sin\alpha}^{\infty}\left(-\sigma\frac{\mathrm{d}\theta}{\mathrm{d}x}\cos\theta\right)\,\mathrm{d}x \\ &= \int_{a\sin\alpha}^{\infty}\left(-\sigma\frac{\mathrm{d}\theta}{\mathrm{d}s}\frac{\cos\theta}{\mathrm{d}x/\mathrm{d}s}\right)\,\mathrm{d}x = \int_{a\sin\alpha}^{\infty}\rho g h\,\mathrm{d}x\end{aligned}$$

from (2.6) and (2.4).

2.3 Negligible surface tension

Taking $\sigma \to 0$, so $\ell \to 0$, (2.15) reduces to $H = -a\cos\alpha$ and floating, (2.16), gives

$$\rho_\mathrm{p} = \frac{\rho}{\pi}\left(\alpha - \frac{1}{2}\sin 2\alpha\right). \tag{2.17}$$

This says that, without surface tension, the centre of the pellet is at depth

$$H = -a\cos\alpha \quad \text{with} \quad 0 \le \alpha \le \pi$$

and

$$\rho_\mathrm{p} = \rho f(\alpha), \qquad \text{defining } f(\alpha) = \frac{1}{\pi}\left(\alpha - \frac{1}{2}\sin 2\alpha\right). \tag{2.18}$$

Note that

$$\begin{cases} \dfrac{\mathrm{d}f}{\mathrm{d}\alpha} = \dfrac{1}{\pi}(1-\cos 2\alpha) > 0 \text{ for } 0 < \alpha < \pi\,, \\ f(0) = 0\,,\ f(\pi/2) = 1/2\,,\ f(\pi) = 1 \\ 0 < f(\alpha) < 1 \text{ for } 0 < \alpha < \pi\,, \end{cases} \tag{2.19}$$

see Fig. 5.

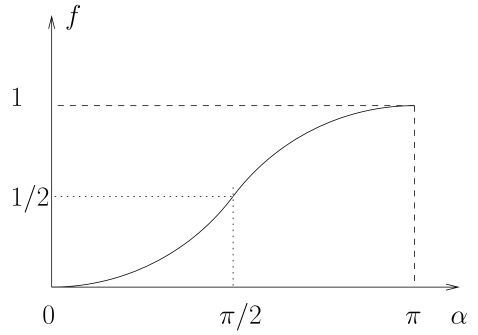

Figure 5: *Graph of the function $f(\alpha)$ (f gives the pellet density in terms of the position angle α in the absence of surface tension).*

Clearly $\mathrm{d}H/\mathrm{d}\alpha = a\sin\alpha > 0$ for $0 < \alpha < \pi$, $H(0) = -a$, $H(\pi/2) = 0$ and $H(\pi) = a$. We get the expected result that as long as the density of the pellet, which must be non-negative, is no greater than that of water, $0 \le \rho_\mathrm{p} \le \rho$, the pellet can float. Moreover: an increased pellet density leads to a lower floating position; $\rho_\mathrm{p} \to 0$ corresponds to $H \to -a$ (with zero density it sits on the surface of the water like a balloon); $\rho_\mathrm{p} \to \rho$ corresponds to $H \to a$ (the pellet becomes totally submerged and just reaches the surface of the water). Fig. 6 shows different cases. Note that, for this case, if, and how, the pellet floats has nothing to do with the pellet size, a.

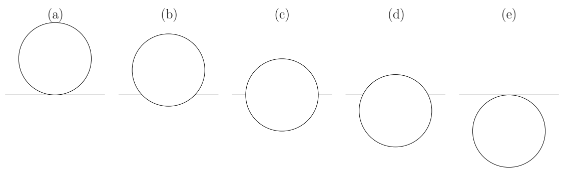

Figure 6: *Floating pellet without surface tension: (a) $\rho_\mathrm{p} = 0$ ($\alpha = 0$); (b) $0 < \rho_\mathrm{p} < \rho/2$ ($0 < \alpha < \pi/2$); (c) $\rho_\mathrm{p} = \rho/2$ ($\alpha = \pi/2$); (d) $\rho/2 < \rho_\mathrm{p} < \rho$ ($\pi/2 < \alpha < \pi$); (e) $\rho_\mathrm{p} = \rho$ ($\alpha = \pi$).*

3 How Flotation Depends on Surface Tension

With significant surface tension, $\sigma > 0$, the floating position, *i.e.* the angle α, is related to the pellet density through (2.16) and (2.15). These give

$$\pi\rho_\mathrm{p} g a^2 = \rho g a\left(a\left(\alpha - \frac{\sin 2\alpha}{2}\right) - 4\ell\sin\alpha\cdot\cos\left(\frac{\alpha+\varphi}{2}\right)\right) - 2\sigma\sin(\alpha+\varphi)$$

which can be rewritten as

$$R = f(\alpha) - \frac{1}{\pi}\left(4L\sin\alpha\cdot\cos\left(\frac{\alpha+\varphi}{2}\right) + 2L^2\sin(\alpha+\varphi)\right), \tag{3.20}$$

where

$$\begin{cases} R = \dfrac{\rho_\mathrm{p}}{\rho} & \text{is the ratio of the pellet and water densities,} \\ f(\alpha) = \dfrac{\alpha - \frac{1}{2}\sin 2\alpha}{\pi} & \text{as in (2.18),} \\ L = \dfrac{\ell}{a} = \dfrac{\sqrt{\sigma/\rho g}}{a} & \text{is the ratio of the length scale of the meniscus to the pellet size.} \end{cases}$$

The dimensionless quantity L can be thought of as a measure of the importance of surface tension. If L is small, we can regard the surface tension as being weak, or the pellet as large. If L is large, the surface tension should be thought of as strong or the pellet as small. (This latter case will be true for insects such as pond skaters which can "walk" on water.) For the pellets of interest, L is likely to be around 1, so surface tension is important but does not dominate.

Floating is now controlled by (3.20). This equation could be solved numerically to find α from known values of the dimensionless quantities L and R, and contact angle φ. Equivalently, for given L and φ, α can be varied from 0 to π to see what density ratios (and hence densities) allow floating; the results of such calculations can be plotted graphically.

It can be noted that for $\alpha = \pi$, $R = 1 + 2L^2 \sin\varphi$ so, at least for $0 < \varphi < \pi$, the presence of surface tension allows pellets with density greater than that of water ($R > 1$) to float. (Intuitively, it is to be expected that a higher contact angle φ makes the pellet more likely to float, in other words higher values of R and ρ_p are possible, as the water attracts the pellet less, or repels it more.) In fact it only makes sense to take $\alpha = \pi$ for $0 < \varphi \le \pi/2$ because, for $\pi/2 < \varphi \le \pi$, there will be some position angle α_c, $\pi/2 < \alpha_\mathrm{c} < \pi$, such that the water surfaces on the two sides of the pellet will overhang sufficiently to touch at some point (x, z) with $x = 0$ and $z > 0$, see Fig. 7.

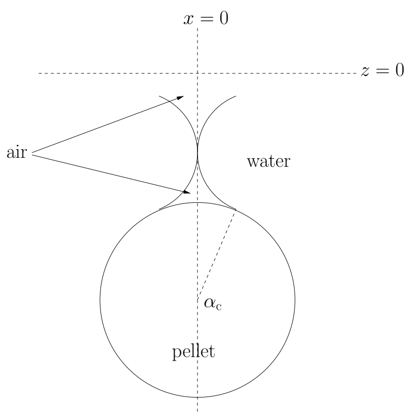

Figure 7: *A critical case, with $\pi/2 < \varphi \le \pi$, with the free water surface touching itself when position angle $\alpha = \alpha_\mathrm{c}$, $\pi/2 < \alpha_\mathrm{c} < \pi$.*

However, it is clear from Archimedes principle that, since there is air lying below the undisturbed level $z = 0$, R is again greater than 1.

Rather than consider (3.20) in full generality, attention is focused on special cases for simplicity but some graphs illustrating the behaviour of (3.20) are plotted in Sec. 5. One such particular case is when water wets the pellet, $\varphi = 0$. Now

$$R = f(\alpha) - \frac{1}{\pi}\left(4L\sin\alpha \cdot \cos\frac{\alpha}{2} + 2L^2\sin\alpha\right).$$

Since $\sin\alpha \cdot \cos\frac{\alpha}{2} = \sin\frac{\alpha}{2} \cdot \cos^2\frac{\alpha}{2} \ge 0$ for $0 \le \alpha \le \pi$, it is apparent that $R \le f(\alpha)$ and that the maximum floating density is given by $\alpha = \pi$: $R = 1$ and $\rho_\mathrm{p} = \rho$. This should be expected as, for $0 < \alpha < \pi$, *i.e.* $0 < \rho_\mathrm{p} < \rho$, the free-surface slope at the the pellet, θ^*, is negative and surface tension pulls the pellet down (see Fig. 8).

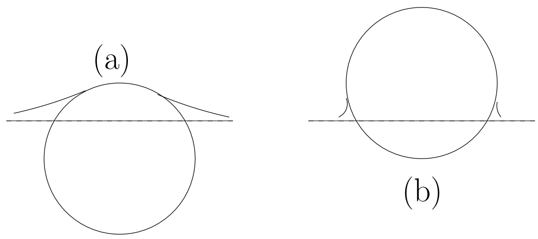

Figure 8: *A floating pellet with contact angle $\varphi = 0$: (a) $\pi/2 < \alpha < \pi$; (b) $0 < \alpha < \pi/2$.*

The other extreme is $\varphi = \pi$, when the water acts to expel the pellet, see Fig. 9.

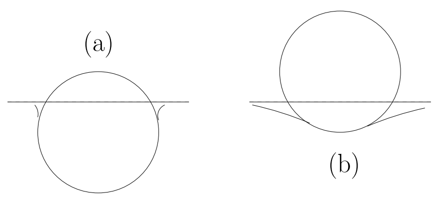

Figure 9: *A floating pellet with contact angle $\varphi = \pi$: (a) $\pi/2 < \alpha < \pi$; (b) $0 < \alpha < \pi/2$.*

Although it is expected, physically, that increasing φ, will increase the maximum pellet density which can be supported, this is only demonstrated here for $0 \le \varphi \le \pi/2$; this avoids any difficulty with one part of the free surface touching another part above the pellet, as noted earlier, for $\varphi \ge \pi/2$.

It has already been observed that for $0 < \varphi < \pi$, $R > 1$ for some α: for $0 < \varphi < \pi/2$ there is some α_m with

$$R_\mathrm{m}(\varphi) = \max_{0 \le \alpha \le \pi}\{R(\varphi, L, \alpha)\} = R(\varphi, L, \alpha_\mathrm{m}) > 1$$

(clearly $\pi/2 < \alpha_\mathrm{m} < \pi$ here). From (3.20), $R_\mathrm{m} > 1$ requires, since $f(\alpha) \le 1$,

$$4L\left(\sin\alpha_\mathrm{m} + L\sin\left(\frac{\alpha_\mathrm{m} + \varphi}{2}\right)\right)\cos\left(\frac{\alpha_\mathrm{m} + \varphi)}{2}\right) < 0 \tag{3.21}$$

Because $0 < \alpha_\mathrm{m} < \pi$ and $0 < (\alpha_\mathrm{m} + \varphi)/2 < \pi$, $\sin\alpha_\mathrm{m} > 0$ and $\sin((\alpha_\mathrm{m}+\varphi)/2) > 0$, and (3.21) gives $\cos((\alpha_\mathrm{m}+\varphi)/2) < 0$ and hence $\alpha_\mathrm{m} + \varphi > \pi$. Then

$$\begin{aligned}\frac{\mathrm{d}R_\mathrm{m}}{\mathrm{d}\varphi} &= \left.\frac{\partial R_\mathrm{m}}{\partial\varphi}\right|_{\alpha=\alpha_\mathrm{m}} \\ &= \frac{2L}{\pi}\left(\sin\alpha_\mathrm{m}\cdot\sin\left(\frac{\alpha_\mathrm{m}+\varphi}{2}\right) - L\cos(\alpha_\mathrm{m}+\varphi)\right) > 0,\end{aligned}$$

since $0 < \alpha_\mathrm{m} < \pi$, $0 < (\alpha_\mathrm{m}+\varphi)/2 < \pi$, and $\pi < \alpha_\mathrm{m} + \varphi \le \alpha_\mathrm{m} + \pi/2 < 3\pi/2$.

This means that for a given L, the largest density of pellet which can be supported with $0 \le \varphi \le \pi/2$ is that for $\varphi = \pi/2$.

We now concentrate our attention on this special value of $\pi/2$ for the contact angle. This special case avoids any possibility of having self-intersecting water surfaces, either above the pellet (noted above) for $\pi/2 < \varphi \le \pi$ or below for $0 \le \varphi < \pi/2$ (which would need a negative density for the pellet!).

4 Right-Angled Contact Angles

With $\varphi = \pi/2$, (3.20) becomes

$$R = f(\alpha) - \frac{2L}{\pi}\left(2\sin\alpha\cdot\cos\left(\frac{\alpha}{2}+\frac{\pi}{4}\right) + L\cos\alpha\right). \tag{4.22}$$

The change from the surface-tension-free density ratio is then given by the function

$$g(\alpha; L) = 2\sin\alpha\cdot\cos\left(\frac{\alpha}{2}+\frac{\pi}{4}\right) + L\cos\alpha \tag{4.23}$$

and which is of the form sketched in Fig. 10.

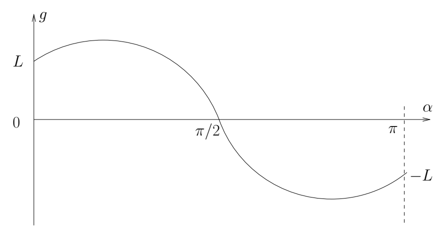

Figure 10: *Graph of g as a function of α.*

Note that:

- $g > 0$ for $0 \le \alpha < \pi/2$; surface tension pulls the pellet down in this case (Fig. 11(a));
- $g = 0$ for $\alpha = \pi/2$; surface tension has no effect, with the water surface being flat ($h \equiv 0$) (Fig. 11(b));
- $g < 0$ for $\pi/2 < \alpha \le \pi$; surface tension now pulls the pellet up (Fig. 11(c));
- $\mathrm{d}g/\mathrm{d}\alpha > 0$ for $\alpha = \pi$.

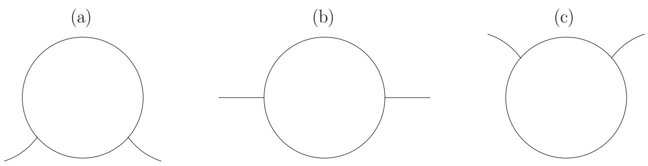

Figure 11: *Sketches of the free surface near the pellet with contact angle $= \pi/2$.*

Then the maximum of R is achieved at some α_m, with $\pi/2 < \alpha_\mathrm{m} < \pi$, since

$$\begin{cases} R \le f(\alpha) \le \dfrac{1}{2} \quad \text{for} \quad 0 \le \alpha \le \dfrac{\pi}{2}, \\ \left.\dfrac{\partial R}{\partial\alpha}\right|_{\alpha=\pi} = f'(\pi) - \dfrac{2L}{\pi}\left.\dfrac{\partial g}{\partial\alpha}\right|_{\alpha=\pi} < f'(\pi) = 0 \\ R|_{\alpha=\pi} = f(\pi) - \dfrac{2L}{\pi}\left.\dfrac{\partial g}{\partial\alpha}\right|_{\alpha=\pi} < f(\pi) = 1. \end{cases}$$

It is clear that this maximum, R_m, has value $R_\mathrm{m} = R(\alpha_\mathrm{m}) > 1$.

It is easily seen, in this case, that increasing surface tension or decreasing pellet size (making L larger) raises the maximum density which can be supported. For α near α_m, $\pi/2 < \alpha < \pi$ so the terms in (4.22) due to surface tension, $\frac{4L}{\pi}\sin\alpha\cdot\left(-\cos\left(\frac{\alpha}{2}+\frac{\pi}{4}\right)\right) + \frac{2L^2}{\pi}(-\cos\alpha)$ are positive, and are then clearly increasing functions of L. Conversely, decreasing L, which corresponds to increasing the pellet size (or decreasing surface tension) leads to a smaller density of pellet which is able to float.

5 Numerical Calculations of Supported Densities

We conclude by plotting some graphs of pellet density, R, against floating-position angle α.

The first set of graphs, Fig. 12, shows graphs for the case of the normal contact angle, $\varphi = \pi/2$, as discussed in Sec. 4, for different values of L. Note how the maximum density ratio R increases with dimensionless surface tension L. The dashed line in Fig. 12 is a blow-up of the zero-surface-tension case. In this figure, and others below, negative densities are indicated in places. These are not of physical interest here and would correspond to a pellet being pulled up by some external force.

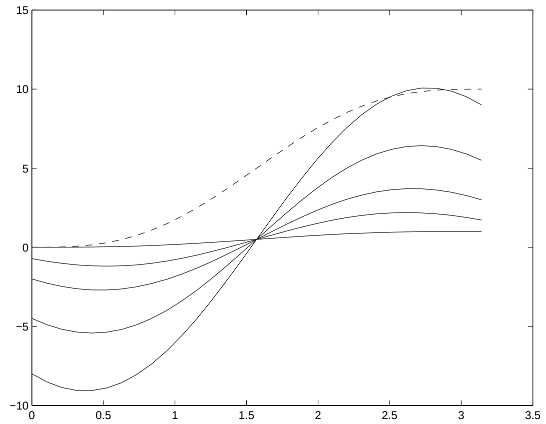

Figure 12: *Plots of the floating density ratio, R, (vertical axis) vs. position angle, α, (horizontal axis) for contact angle* $\varphi = \pi/2$. *Values of dimensionless surface tension, L, are* 0, 0.6, 1, 1.5 *and* 2 *(increasing L corresponds to increasing amplitude). The broken curve shows* $10R$ *for* $L = 0$.

The second set of graphs, Fig. 13, again shows graphs of the density ratio, but taking five different values of contact angle with a fixed value of $L = 1$. Because of having a self-intersecting water surface, below or above the pellet, the extreme left-hand parts of curves 1 and 2 (contact angle = 0 and $\pi/4$) and the extreme right-hand parts of curves 4 and 5 (contact angle = $3\pi/4$ and π) have no physical significance. Note that, with the exception of the zero-contact-angle case, curve 1, $\varphi = 0$, the maximum of the density, *i.e.* the maximum of R, is raised above 1 by the effect of the surface tension. We can also observe that this maximum floating density is raised by having an increased contact angle.

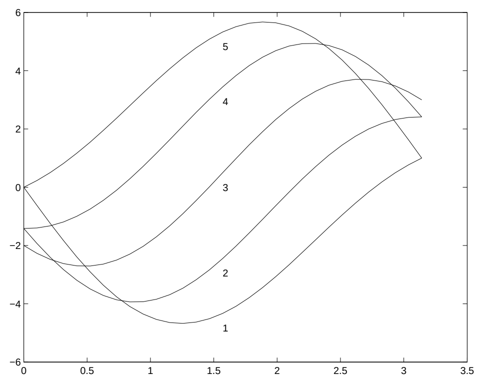

Figure 13: *Plots of the floating density ratio, R, (vertical axis) vs. position angle, α, (horizontal axis) for dimensionless surface tension* $L = 1$. *Values of contact angle* φ *are* 0 *(curve 1),* $\pi/4$ *(curve 2),* $\pi/2$ *(curve 3),* $3\pi/4$ *(curve 4) and* π *(curve 5).*

The final pair of graphs, Fig. 14, show how surface tension affects pellet buoyancy for the two special cases of $\varphi = 0$ and $\varphi = \pi$. The left-hand graphs show how with $L = 1$ the pellet is pulled down when wetting occurs ($\varphi = 0$): R for $L = 1$ is below that for $L = 0$ (zero surface tension) and the maximum floating density ratio is $R = 1$ for both cases. The right-hand graphs show how with $L = 1$ the pellet is pushed up for a hydrophobic surface ($\varphi = \pi$): R for $L = 1$ is above that for $L = 0$ (zero surface tension) and the maximum floating density ratio for $L = 1$ is now much bigger than 1.

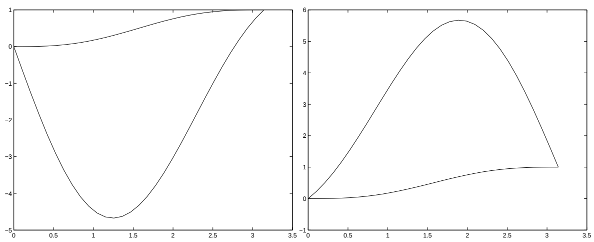

Figure 14: *Plots of the floating density ratio, R, (vertical axis) vs. position angle, α, (horizontal axis) for contact angle* = 0 *(left-hand graphs) and contact angle* = π *(right-hand graphs). In the left-hand graphs the upper curve is for* $L = 0$ *and the lower one is* $L = 1$. *In the right-hand graphs the lower curve is for* $L = 0$ *and the upper one is* $L = 1$.

6 Consequences and Discussion

The results of Secs. 4 and 5 indicate that surface tension can play an important role helping objects which are heavier than water to float. To ensure that pellets of size of a few millimetres sink, if their density is comparable with but larger than that of water, their composition would ideally be such that the contact angle is small. Of course control of contact angle is unlikely to be practical as the make-up of the pellets will be determined by the nature of the fish food.

The significance of surface tension is also suggested by the sizes of quantities involved. Typically, with water density $\rho = 10^3\,\mathrm{kg\,m^{-3}}$, acceleration due to gravity $g = 10\,\mathrm{m\,s^{-2}}$, surface tension $\sigma = 7\times10^{-2}\,\mathrm{N\,m^{-1}}$, and a pellet radius $a = 3 \times 10^{-3}\,\mathrm{m}$, the dimensionless surface tension is $L \approx 1$. Note that a pellet can be expected to have density fairly close to, but rather greater than, that of water, say $R = \rho_{\mathrm{p}}/\rho \approx 1.2$. Fig. 13 indicates that for such a pellet to sink its contact angle should be significantly less than $\pi/4$.

The results show (see Fig. 12) that the maximum density depends crucially upon the dimensionless surface tension: small objects can float with greater density than larger ones. This indicates a possible reason for problems with testing the floatation of pellets in small bodies of water, such as buckets, compared with their use on large expanses. If several pellets are put together onto a water surface they can act like a single large object, giving a small value of L and hence a good chance of sinking. With widely scattered pellets, each acts a single individual, with a large value of L, and they can be prone to floating.

Of course all the work here has been for the effectively two-dimensional case of a long cylindrical object. However, the same qualitative behaviour is to be expected for more general shapes: the larger the body (and the smaller the contact angle), the smaller the density has to be for it to float. It will be possible to do similar calculations as here, and to get to the same qualitative conclusions, for spherical pellets when there is axial symmetry about the vertical (z) axis.

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CIM Early History

The near origins of CIM can be traced to the end of 1990 at the foundation of the European Mathematical Society (EMS) and to an initiative of the Portuguese Mathematical Society (SPM, Sociedade Portuguesa de Matemática), which was one of the EMS founding members.

Since then, the need of a forum of European Research Centres in the Mathematical Sciences was recognized and the SPM had promoted the idea of creating a Portuguese Center. In particular, it would have the aim to cooperate with similar centres and to enhance the development and promotion of research in Mathematics in Portugal, as well as to assist mathematicians in developing countries, priority being given to the Portuguese speaking countries in Africa (Angola, Mozambique, Cape Verde, Guinea-Bissau, São Tomé and Príncipe).

Several mathematicians gave their personal and institutional support to the idea, such as J. M. Lemaire, at the time director of the CIMPA from Nice (France) who came to Portugal for a visit in 1991, Angelo Marzollo from UNESCO, and F. Hirzbruch, the first president of the EMS, who expressed his support on behalf of the Society.

During 1992 a national discussion took place among the Portuguese mathematical community and the Department of Mathematics of the University of Coimbra offered to house the future Centre on the campus of its Astronomical Observatory. Delegates from the Mathematics Departments of all public Portuguese Universities, the president of the Portuguese Mathematical Society and a representative of the Academy of Sciences of Lisbon were invited to participate in the constitutive meetings. Indeed almost all of them had participated in the two meetings that have created the consensus that the new Centre should promote activities to encourage the development of Mathematical Sciences in general and to foster international cooperation, as well as to help the improvement of the level of Mathematics and its Applications in Portugal.

CIM was legally incorporated on December 3, 1993. Until the election of its first direction, on July 1996, CIM was run by an organizing committee formed by the president of the Portuguese Mathematical Society and other mathematicians from the Universities of Coimbra, Lisbon, Porto and Minho. Since then CIM is managed by a Board of Directors elected by the associates in the General Assembly.

CIM started to publish its Bulletin in December 1996, the first meetings were organised in the following year and the first Thematic Term was held in 1998. It has been regularly in operation as can be seen in the list of events, in particular, with sponsorships from the Calouste Gulbenkian Foundation and from the Portuguese Foundation for Science and Technology. In March 2008, CIM has hosted the annual ERCOM meeting in Coimbra, Portugal.

Math in the Media

Originally published by the American Mathematical Society in MATH in the MEDIA, a section of the AMS Website, www.ams.org/mathmedia, edited by Tony Phillips. Reprinted with permission.

"Samurai mathematician".

Seki Takakazu (Seki Kowa). Image from Tensai no Eiko to Zasetsu by Masahiko Fujiwara (Shincho-sha, Tokyo, 2002), used with permission.

"Samurai Mathematician Set Japan Ablaze With Brief, Bright Light" is the title of a History of Science News-Focus piece in the October 10 2008 Science. Dennis Normile reports from Tokyo, site of a history of mathematics conference last August dedicated to the memory of Seki Takakazu. Seki (c. 1642-1708, also Seki Kowa) was in fact born into a samurai family; his portrait includes the the two swords (daisho) attesting his warrior status. That he "set Japan ablaze" may be an overstatement, but the "bright light" is appropriate: Seki (an almost exact contemporary of Leibniz, but working in complete isolation from European mathematics) "devised new notation for handling equations with several variables and developed solutions for equations with an unknown raised to the fifth power". Furthermore, according to Normile, "His most significant work focused on determinants ... , a field he pioneered a year or two ahead of ... Leibniz". The word "brief" is, unfortunately, also correct. Seki was ahead of his time, and soon after his death, even though his works were gathered and preserved by his students, "the Japanese mathematical tradition hit a dead end". Normile quotes the science historian Hikosaburo Komatsu: Seki's more erudite work "was too difficult for people to pick up and carry forward". Only now are his most innovative contributions being recognized. Namely, his "discovery around the year 1680 of a general theory of elimination, a method of solving simultaneous equations by whittling down the number of unknown quantities one by one". According to Komatsu, the work had been overlooked because it led to calculations "almost beyond human capabilities".

The diagonalization of physics. Cantor's diagonal argument occurs in his (second, 1891) proof of the uncountability of the real numbers. As Wikipedia tells us, "it demonstrates a powerful and general technique, which has since been reused many times in a wide range of proofs, also known as diagonal arguments ... The most famous examples are perhaps Russell's paradox, the first of Gödel's incompleteness theorems, and Turing's answer to the [Halting Problem]". Now this technique has been extended to the real world, or at least to our understanding of it. Philippe Binder reports in a Philosophy of Science *News & Views* piece in *Nature* (October 16, 2008) on work of the physicist/generalist David Wolpert published earlier this year (*Physica D* **237** 1257-1281). According to Binder, Wolpert has demonstrated "that the entire physical Universe cannot be fully understood by any single inference system that exists within it". How does he get there? In Binder's telling, Wolpert "introduces the idea of inference machines – physical devices that may or may not involve human input – that can measure data and perform computations, and that model how we come to understand and predict nature". These machines process U, "the space of all world-lines (sequences of events) in the Universe that are consistent with the laws of physics". Wolpert defines strong inference as "the ability of one machine to predict the total conclusion function of another machine for all possible set-ups". And then he uses diagonalization to prove:

- Let C_1 be any strong inference machine for U. There is another machine, C_2, that cannot be strongly inferred by C_1.
- No two strong inference machines can be strongly inferred from each other.

"The two statements together imply that, at best, there can be only a 'theory of almost everything'." Binder goes on to give some smaller-scale possible instantiations of the phenomenon.

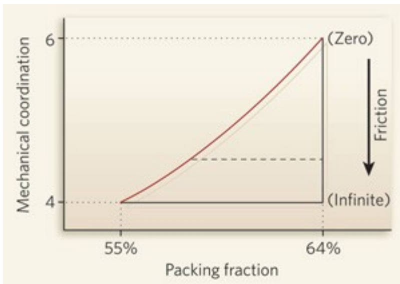
Solzhenitsyn mathematician. *Paris-Match* ran a photo essay on Alexander Solzhenitsyn (died August 3, 2008) in its August 7-13 issue. It included this picture of the author tutoring his children in mathematics.

Solzhenitsyn teaching his children the derivation of the quadratic formula. ©1981 Harry Benson.

Paris-Match's caption reads: "1982: pour ses trois fils il retrouve le tableau noir du professeur de maths qu'il a été". For more details we can turn to his 1970 Nobel Prize Autobiography.

- "I wanted to acquire a literary education, but in Rostov such an education that would suit my wishes was not to be obtained. ... I therefore began to study at the Department of Mathematics at Rostov University, where it proved that I had considerable aptitude for mathematics. But although I found it easy to learn this subject, I did not feel that I wished to devote my whole life to it. Nevertheless, it was to play a beneficial role in my destiny later on, and on at least two occasions, it rescued me from death. For I would probably not have survived the eight years in camps if I had not, as a mathematician, been transferred to a so-called sharashia, where I spent four years; and later, during my exile, I was allowed to teach mathematics and physics, which helped to ease my existence and made it possible for me to write...."
- "In 1941, a few days before the outbreak of the war, I graduated from the Department of Physics and Mathematics at Rostov University. At the beginning of the war, owing to weak health, I was detailed to serve as a driver of horsedrawn vehicles during the winter of 1941-1942. Later, because of my mathematical knowledge, I was transferred to an artillery school ..." [He is arrested in 1945 for having written "certain disrespectful remarks about Stalin" in letters to a friend, and sentenced to eight years in a detention camp.]
- "In 1946, as a mathematician, I was transferred to the group of scientific research institutes of the MVD-MOB (Ministry of Internal Affairs, Ministry of State Security). I spent the middle period of my sentence in such "SPECIAL PRISONS" (The First Circle)". [A month after serving out his sentence, he is exiled for life to Kok-Terek (southern Kazakhstan). "This measure was not directed specially against me, but was a very usual procedure at that time". Stalin dies in 1953 but Solzhenitsyn's exile lasts until June, 1956.]
- "During all the years of exile, I taught mathematics and physics in a primary school and during my hard and lonely existence I wrote prose in secret ..."

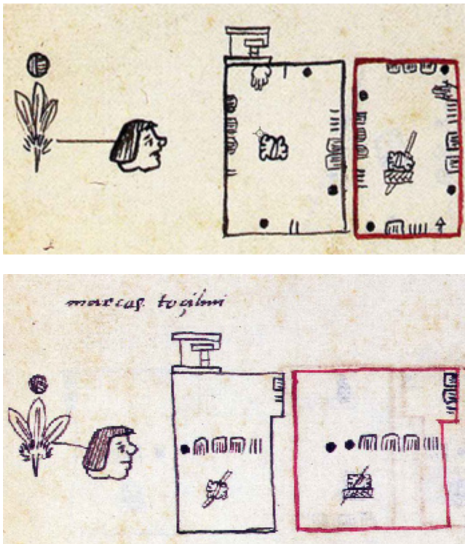
"Mathematics of the spheres". The most efficient way to pack equal-sized spheres in three dimensions involves placing them in layers along a hexagonal tiling of the plane and fitting adjacent layers together so that each sphere in one layer fits into the dimple determined by 3 adjacent spheres in the layer below. In these arrangements each sphere touches 12 others, and the average density, or *packing fraction* (volume of spheres)/(volume of ambient space) is approximately 0.74. Thomas Hayes' 1998 proof that these packings are in fact optimal (the Kepler Conjecture) is now generally accepted. But suppose spheres are dumped into a container without being carefully stacked. What density can such a *random packing* expect to achieve? Experimentally it ranges between 55% (*random loose packing*) and 64% (*random close packing*). Clearly friction will play a role, but how? In the May 29 2008 *Nature*, a CCNY-Fortaleza team (Chaoming Song, Ping Wang, Hernán A. Makse) use statistical mechanics to describe a phase space for packings, and to give an intelligible model for these questions.



The phase space for sphere packings. For each value of the friction coefficient the dashed line represents the possible packing fractions that can be realized by a stable sphere packing. The mechanical coordination number, the average number of adjacent spheres that contribute to holding a given sphere in place, varies monotonically with friction. This image is from Francesco Zamponi's "News and Views" analysis of the Song-Wang-Makse paper in the same issue: *Nature* **453** 606-607, and is used with permission.

"Mathematics of the spheres" is the way these items were characterized in the Nature "Editor's Summary".

Aztec area algorithms. The Aztec numbering system is pretty well understood: it is a base-20 place-value system with a symbol for zero. But some extra numerical symbols ("arrow", "hand", "heart", "bone") appear on land surveys, where they seem to represent quantities smaller than 1. An explanation for these mysterious symbols was recently (April 4, 2008) published in Science. Barbara Williams (Wisconsin-Rock County) and Maria del Carmen Jorge y Jorge (UNAM) exploited the data from the *Codex Vergara* (in the Bibliothèque Nationale) and the *Codice de Santa Maria Asuncion* (Fondo Reservado de la Biblioteca Nacional de Mexico, UNAM), where a number of plots are recorded with their side measurements *and their areas*. The areas are invariably whole numbers of the squared unit; by a process of trial and error they were able to reconstruct some of the algorithms the Aztecs had used to calculate the areas, and work backwards to figure out values for the unknown symbols.



Part of the holdings of a sixteenth-century Mexican landowner, shown with linear side measurements and with areas. Details of two pages from the *Codice de Santa Maria Asuncion* (Fondo Reservado de la Biblioteca Nacional de Mexico, UNAM). The sides of the plots are labeled with their lengths in Aztec numeration: Solid dot = 20, vertical line = 1, grouped by 5s. The areas are written in Aztec place-notation with the 20s place in the center and the 1s place in a tab on the upper right. Some of the notation for "fractional" length measurements appears in this chart: the arrow and the hand. The dimensions of the right-most plot are, clockwise from the top, 35, 34+hand, 29+arrow, 39; its area is given as $59 \times 20 + 12$ or 1192 square units. In the left-most plot the 17 is presumably a copying error for 37; otherwise area 767 is impossible. Images courtesy of Prof. Maria del Carmen Jorge.

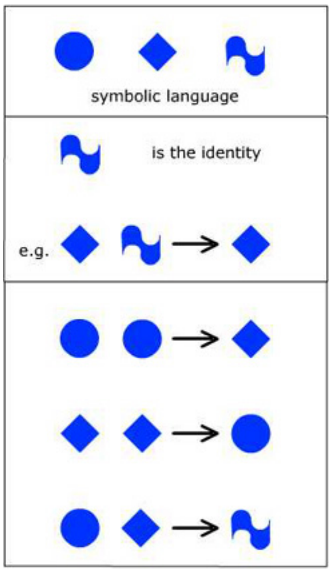
- Starting with the simplest example: the *Codex Vergara* contains many examples of plots with length 20, width 10 and area 200. It also has an example of a plot with length = 20, width = $10+ \rightarrow$, and area = 210. The authors infer that in all these cases the Aztecs used "area = length times width", and that consequently $\rightarrow$ is worth 1/2 the unit.

- In a more complex example, the plot is a near-trapezoid with sides 26, 32, 30, 10 and area 588. They infer that the Aztecs are using the surveyor's rule: "area = the product of the averages of the opposite sides", because this algorithm is simple and gives that exact answer: $(26+30)/2 \times (32+10)/2 = 588$. Then they consider the quadrilateral with sides 36, 12, 37, 12 and area 438. The only plausible explanation they find is that the surveyor's rule (here identical with the trapezoid rule) was used, with $(36+37)/2 = 36+ \rightarrow$ and $12 \times (36+ \rightarrow) = 432 + 12 \rightarrow = 438$. This implies that the Aztecs used $\rightarrow$ in calculation, and not only in measurement.

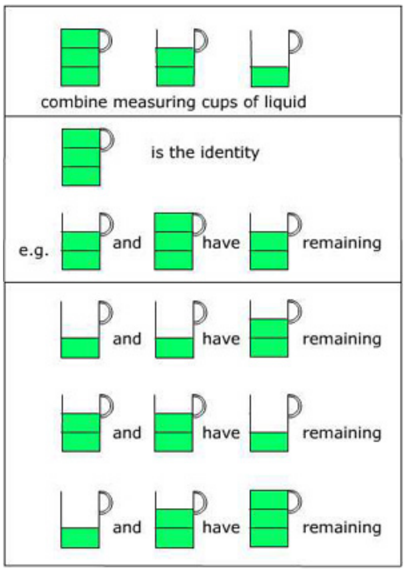
- Other algorithms are similarly inferred. For example the quadrilateral with sides 24, 16, 25, 24 and area 492 was most plausibly calculated with the "triangle rule" (taking it as two right triangles joined at the hypothenuse): $(24 \times 16)/2 + (25 \times 24)/2 = 492$.

As the authors remark, the explanations for the hand (3/5 unit), the heart (2/5 unit) and the bone (1/5 unit) are mathematically less compelling. [In fact, in every case that I checked the author's "calculated value" involves arbitrary approximations and/or roundings before matching with the "recorded area" from the Codex. For example their plot $03 - 030$ has sides 42, 20, 47, 23 and area 1005, for which they use the rule "average of one pair of opposite sides times an adjacent side" as follows, using the arrow ($\rightarrow = 1/2$) and the heart ($(=) = 2/5$): $(23+20)/2 = 21+ \rightarrow \sim 21 + (=)$, $47(21+(=)) = 987 + 47(=) = 987 + 9(5(=)) + 2(=) = 987 + 9X2 + 2(=) = 1005 + 2(=)$ rounds down to 1005. The problem is that there are too many unknowns. We have no clue as to the exact shape of many of the plots. We do not even know whether the surveyors always used a formula going from side lengths to areas or whether other estimates or measurements were involved. But the examples spelled out above do give very strong evidence that sixteenth-century Aztecs had good algorithms for computing areas of rectangles, trapezoids and triangles, and that they could and did calculate with quantities less than the unit. -TP] This article was featured in ScienceNOW ("How Aztecs Did the Math"), and picked up in the Los Angeles Times ("Aztec math finally adds up"), the Scientific American ("Aztec Math Used Hearts and Arrows") and National Geographic News ("Aztec Math Decoded, Reveals Woes of Ancient Tax Time").

Teaching math with concrete examples? "Abstract knowledge, such as mathematical knowledge, is often difficult to acquire and even more difficult to apply to novel situations. It is widely believed that a successful aproach to this challenge is to present the learner with multiple concrete and highly familiar examples of the to-be-learned concept". This is the start of "The Advantage of Abstract Examples in Learning Math" by Jennifer Kaminsky, Vladimir Sloutsky and Andrew Heckler (Center for Cognitive Science, OSU), an Education Forum report in the April 25 2008 Science. As can be surmised from the title, the authors present evidence that this widely shared belief is wrong. symbolic instantiation



Generic Instantiation



Concrete Instantiation

Two ways of presenting the concept commutative group with three elements. In the generic example, the concept is presented as a set of rules (—¿) linking pairs of objects to a third object.

In the concrete example, "participants were told that they needed to determine a remaining amount when different measuring cups of liquid are combined".

In one of their experiments, "undergraduate college students learned one or more instantiations of a simple mathematical concept. They were than presented with a transfer task that was a novel instantiation of the learned concept". The instantiations in question were a "generic" instantiation (top figure above) and three different "concrete" instantiations, one of which is illustrated above (the others involved slices of pizza or tennis balls in a container). They authors report that "all participants successfully learned the material" but that when transfer was tested participants who had been taught the generic condition "performed markedly higher than participants in each of the three concrete conditions". The authors also investigated the advantage of teaching a concrete instantiation and then a generic one, and found that "participants who learned only the generic instantiation outperformed those who learned both concrete and generic instantiations". They conclude that "grounding mathematics deeply in concrete contexts can potentially limit its applicability". [It is curious that the authors did not investigate the standard paradigm: abstract definition followed by concrete example, which has the advantage of showing students an example of how to transfer. -TP]

Non-verbal number acuity counts

An article published online September 7, 2008 by Nature bears the title "Individual differences in non-verbal number acuity correlate with maths achievement". The authors, a Johns Hopkins team led by Justin Halberda, elaborate in the Abstract: "Our results show that individual differences in achievement in school mathematics are related to individual differences in the acuity of an evolutionarily ancient, unlearned approximate number sense". What is this ancient unlearned number sense? There turns out to be an "approximate number system," or ANS, which is "shared by adults, infants and non-human animals". These groups "can all represent the approximate number of items in visual or auditory arrays without verbally counting, and use this capacity to guide everyday behaviour such as foraging". The authors set out to investigate whether this ancestral ability is uniform among humans, and if not whether it correlates with other, more symbolic, mathematical talent.

They studied a group of 64 14-year-olds and measured their "ANS acuity" by trials in which "subjects saw spatially intermixed blue and yellow dots presented on a computer screen too rapidly (200 ms) to serially count. Subjects indicated which colour was more numerous by key press and verbal response". dot pattern

Images like this one were flashed on a screen too rapidly for the dots to be counted. Subjects were asked to estimate which color was more numerous. Here there are 8 yellow dots and 6 blue; ratios varied randomly from 1:2 to 7:8.

The authors discovered a "surprisingly large variation in the ANS acuity". Some subjects could detect excesses as relatively small as 10 over 9 with 75

This research was picked up by Natalie Angier in the September 16 2008 New York Times under the headline "Gut Instinct's Surprising Role in Math".

Midge dynamics in Lake Myvatn.

50 generations of midge population in Lake Myvatn. The solid line represents observations, the dashed line output from the mathematical model with nine tuned parameters. Image courtesy of Anthony Ives.

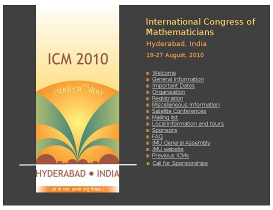
"Mathematics Explains Mysterious Midge Behavior" is the title of an article by Kenneth Chang in the March 7 2008 *New York Times*. At Myrvatn ("Midge Lake") in northern Iceland, during mating season, the air can be thick with male midges (*Tanytarsus gracilentus*), billions of them. Chang quotes Anthony Ives (Wisconsin) "It's like a fog, a brown dense fog that just rises around the lake." And yet in other years, at the same time, there are almost none. Ives was the lead author on a report in *Nature* (March 6 2008) that gave an explanation for this boom-and-bust behavior in which, as Chang describes it, "the density of midges can rise or fall by a factor of a million within a few years." In the *Nature* report ("High-amplitude fluctuations and alternative dynamical states of midges in Lake Myvatn"), Ives and his co-authors characterize the midge ecology as one "driven by consumer-resource interactions, with midges being the consumers and algae/detritus the resources" and they set up a system of three coupled nonlinear difference equations, one each for midges, algae and detritus, to model it. The dynamics of this system include a stable state as well as a stable high-amplitude cycle; small variations in parameters can drive the system from one of those attractors to the other.

Alternative stable states of the midge-algae-detritus model. In the panel on the left, the plane is tangent to the manifold containing the cyclic component of the dynamics around the stationary point. The white region in the plane shows the domain of attraction to the invariant closed set, whereas the region in grey gives the domain of attraction to the outer stable cycle. The red lines give two examples of trajectories that converge to the outer stable cycle. The panel on the right shows the plane in more detail to illustrate the fine structure of the domain of attraction to the invariant closed set. The blue pentagon shows the unstable period 5 cycle that makes up part of the boundary between domains of attraction to the inner invariant closed set and the outer stable cycle. Image courtesy of Anthony Ives.

19-27 August 2010: International Congress of Mathematicians - ICM 2010,

Hyderabad, India.

http://www.icm2010.org.in/



July 18–22, 2011: 7th International Congress on Industrial and Applied Mathematics - ICIAM 2011,

Vancouver, BC, Canada.

http://www.iciam2011.com/

CIM News

The meeting in Óbidos of the EIMI IPCommittee

The Centro Internacional de Matemática (CIM) has organized and sponsored the International Programme Committee meeting of the EIMI study that took place in Óbidos, Portugal, during 2-5 October, 2008. CIM is also hosting the study and conference website http://www.cim.pt/eimi/ where more information can be found and will be posted regularly.

The International Program Committee (IPC) is composed by Alain Damlamian (France, co-chair), Rudolf Strässer (Germany, co-chair), José Francisco Rodrigues (Portugal, host country), Marta Anaya (Argentina), Helmer Aslaksen (Singapore), Gail Fitzsimons (Australia), José Gambi (Spain), Solomon Garfunkel (USA), Alejandro Jofré (Chile), Henk van der Kooij (Netherlands), Li Ta-tsien (China), Brigitte Lutz-Westphal (Germany), Taketomo Mitsui (Japan), Nilima Nigam (Canada), Fadil Santosa (USA), Bernard Hodgson (Ex-officio, ICMI), Rolf Jeltsch (Ex-officio, ICIAM).

From left to wright, upper row: Gail Fitzsimons, José Gambi, Alejandro Jofré, Bernard Hodgson, Taketomo Mitsui, Alain Damlamian, Brigitte Lutz-Westphal, Henk van der Kooij and José Francisco Rodrigues; and lower row: Solomon Garfunkel, Rudolf Strässer, Helmer Aslaksen and Rolf Jeltsch.

The ICMI/ICIAM joint Study on Educational Interfaces between Mathematics and Industry is designed to enable researchers and practitioners around the world to share research, theoretical work, projects descriptions, experiences and analyses. It will consist of two components: the Study Conference and the Study Volume.

The Study Conference will be held in Lisbon, Portugal, on April 19-23, 2010, the number of participants to be invited being limited to approximately 100 people. It is hoped that the Conference will attract not only "experts" but also some "newcomers" to the field with interesting and refreshing ideas or promising work in progress, as well as participants from countries usually under-represented in mathematics education research meetings.

The Study Volume, a post-conference publication, will appear in the New ICMI Study Series (NISS), published by Springer. Acceptance of a paper for the Conference does not ensure automatic inclusion in this book. The Study Volume will be based on selected contributions as well as on the outcomes of the Conference. The exact format of the Study Volume has not yet been decided but it is expected to be an edited coherent book that can hopefully serve as a standard reference in the field for some time.

ICMI http://www.mathunion.org/ICMI/

ICIAM http://www.iciam.org/

EIMI http://www.cim.pt/eimi/

EDUCATIONAL INTERFACES

BETWEEN

MATHEMATICS and INDUSTRY

An ICMI-ICIAM International Study (2008-2011)

Scientific and technological research is the basis for industrial innovation and mathematics is a key technology for the industry, interpreted in the broadest sense as any activity of economical or social value, including the service industry. The range of domains of knowledge and of the economic sector that require a variety of mathematical tools and methodology is enormous. The intimate connections between innovation, science and mathematics also demands new strategies for education of students, including more interdisciplinary training.

Classically students on all levels have been taught the tools of mathematics with little or no mention of real world applications, with little or no contact with what is done in the workplace (be it the classical engineering industry or other more recent activities like biotechnology, biomedicine, financial, insurance and risk sector or consulting engineering companies).

Nowadays one needs the solution of highly complex problems and hence some training to solve such problems, in particular real life problems, has to be given. More and more powerful computers make it possible to treat such complex problems and this is not done using only the shelf software but with innovation, often mathematical innovation.

EIMI (Education Interfaces between Mathematics and Industry) is an international study on Education and Training on Applied and Industrial Mathematics on the secondary and tertiary level, including technical and vocational education. This includes secondary school, high schools and vocational schools, and tertiary education at polytechnics and universities. In addition postgraduate education and retraining during the professional life must also be considered, as well as:

- survey and analysis of experiences, programmes and consortia at regional and world levels, including industrial internships, Mathematics Clinics, modelling camps and summer schools;
- identification, development and assessment of curricula that include innovative applications of mathematics, highlighting industry-driven problems; including undergraduate and postgraduate programmes in conjunction with industry;
- characterizing mathematical literacy at work at different kinds of jobs; what is needed to have professionals of the adequate level;
- students activities and interdisciplinary training; didactic materials to support teaching and learning; high school, undergraduate and graduate mathematical modelling contests (applied mathematics Olympiads);
- how to set up opportunities for secondary school teachers to participate in academic industrial initiatives;
- visions; perspectives from Industry and from Academia.

The EIMI Study is a first joint collaboration between the International Commission on Mathematical Instruction (ICMI, http://www.mathunion.org/ICMI) and the International Council for Industrial and Applied Mathematics (ICIAM, http://www.iciam.org) and it was proposed by the Portuguese National Committee of Mathematicians. It was announced at the 11th International Congress of Mathematical education, ICME-11, July 6-13, 2008, Monterrey, Mexico, and the presentation of the EIMI-study is scheduled for the occasion of the 7th International Congress on Industrial and Applied Mathematics - ICIAM 2011, to be held in July 18-22, 2011, in Vancouver, BC, Canada.

Further information can be obtained in due course from the website (http://www.cim.pt/eimi/) of the study and/or:
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