

HEAT TRANSFER DIVISION

Fall 2006

The Heat Transfer Division's objective is to enhance the theory and application of heat transfer in equipment and thermodynamic processes in all fields of mechanical engineering and related technologies.

Chair's and Past Chair's Remarks

State of the Division

We are happy to report that, by all metrics, the Heat Transfer Division is not only healthy, but thriving. The HTD has had a long history of leadership in ASME, and we continue in that role. Dissemination of technical publications through conferences and the *Journal of Heat Transfer* is very strong. Our conferences are well attended and are providing much-needed revenue to the Division. With improvements to our Division's custodial fund, we can now undertake initiatives to further improve service to our members (such as encouraging undergraduate students to pursue our field with travel funds to the IMECE). The HTD remains one of the most active Divisions in the IMECE. Despite these successes, we have more to do to ensure that all sectors of our division do receive value for their membership in the HTD.

Publications and Conferences

The *Journal of Heat Transfer* is one of the top two journals published by the ASME, measured by impact factor, profitability, and stature. This year it became a monthly journal to increase its impact to the community. At the 2004 IMECE, the HTD presented 252 papers; at the 2005 IMECE, there were 240 papers; and based on abstract submissions, we anticipate an even greater presence at the 2006 IMECE. At the recent IMECEs, the HTD presented more papers and had more attendees than any other division. We are continuing to reach out to other groups to join with us for our summer meeting (as we did with the Fluids Engineering Division in 2004 in Charlotte). In 2005, InterPack co-located with our 2005 Summer Heat Transfer Conference—nearly 1000 people attended, and nearly 500 papers were presented! Because of this success, we again will co-locate these two conferences in 2007 (July in Vancouver); joining us will be the Japanese Society of Mechanical Engineers.

Conference organization from the volunteer (technical) side, as well as from the administrative side (ASME staff), is a daunting and complex activity. Over the past several years, we have attempted to ensure more value for your registration fee while keeping conference quality high. We have had numerous discussions over the past few years about the desirability of finding someone other than ASME to run our conferences. With various recent personnel changes at ASME, we have had, at times, uneven support for our division and conferences. As a result, and after much serious consideration and discussion, we have decided to go with an outside vendor to run our 2007 Summer Heat Transfer Conference. The group is experienced, and we are quite optimistic that we will, again, put on an excellent conference.

Heat Transfer Division Structure

The ASME has undergone changes in its organization and operation; most of these changes will be transparent to the vast majority of HTD members. Because of these changes, it appeared that the HTD would need to join the other divisions of the Basic Engineering Group to form an "institute," which could have affected the HTD's operation. For the time being, however, that will not happen. The discussions about that possibility, however, encouraged us to look at our structure and operation, which have remained static for as long as most of us can remember. The main question to be answered is: How can the HTD best serve ALL of its members? The K-2 Long Range Planning Committee is leading this assessment, and they present a brief report in another part of this newsletter.

Our Collective Future

The success of the HTD lies in the strength of its committee structure and the active involvement of many members. Nevertheless, we need to improve. We currently serve well the portion of our community who are involved in fundamental research, and many from this community are active in the HTD. We do a lesser job, however, for

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Chair's and Past Chair's Remarks

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those involved in applied research. Thus, we are exploring alternative approaches to reach out to that community. Yogesh Jaluria, senior technical editor of the *Journal of Heat Transfer*, is chairing a committee to determine how we could include more applied research papers in either the *Journal of Heat Transfer* or another journal, while maintaining the high quality the Journal is known for. For conferences, technical program chairs have been instructed to encourage the submission and presentation of applied research papers. On all administrative committees (e.g., Awards and Honors, Executive Committee), we are reaching out to industrial members to become more involved. The only way for the HTD to better serve the industrial community is if industrial members become involved in our technical committees. The HTD Executive Committee has been holding an Open Forum session at our summer meetings and IMECEs, and has directly engaged each committee chair to improve communication and encourage dialogue and discussion on these important topics. We actively seek your input and suggestions as we map our collective future.

With changes already implemented and others being considered, we believe that service to our HTD members will be improved. If you have suggestions for additional changes, please feel free to contact us. It has been our pleasure to serve the Division, and we strongly request all members to be as active as possible – we need your engagement to ensure the HTD continues to thrive.

*Michael K. Jensen,
Chair 2005-2006*

*Russell D. Skocypec,
Past Chair 2005-2006*

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2005 Awards

The following awards were recognized at the 2005 IMECE and elsewhere:

New ASME Fellows

Ali Abdul-Aziz
Thomas P. Giolda
Larry K. Matthews
Alfonso Ortega
Aleksandar G. Ostrogorsky
Rangarajan Pitchumani
Ali A. Rostami
Arthur E. Ruggles
Srikantiah Srinivasa Murthy
Zhuomin Zhang

Journal of Heat Transfer Outstanding Reviewers

Kalyan Annamalai
Glen E. Thorncroft
Noam Lior
Li Shi

2005 HTD Best Paper Award

Yuichi Mitsutake and
Masanori Monde for "Ultra
High Critical Heat Flux During
Forced Flow Boiling Heat
Transfer with an Impinging Jet,"
in *J. Heat Transfer* Vol. 125,
pp. 1038-1045, 2003

2005 HTD Classic Paper Award

E. M. Sparrow for "A New and
Simpler Formulation for Radiative
Angle Factors," in *J. Heat Transfer*
Vol. 85, pp. 81-88, 1963

Bergles-Rohsenow Young Investigator Award

Sylvie Lorente, National Institute of
Applied Sciences, Toulouse, France

K-14 Committee's

Warren M. Rohsenow Prize for Best Presentation

Huitao Yang, Hamn-Ching Chen,
Je-Chin Han, and Hee-Koo Moon
for "Numerical Prediction of Film
Cooling and Heat Transfer on the
Leading Edge of a Rotating Blade
in a 1-1/2 Turbine Stage," at the
2004 IMECE

HTD Distinguished Service Award

William Begell

Heat Transfer Memorial Awards

A. Haji-Sheikh (Science)
M. Modest (Art)
W. Shyy (General)

HTD Committee Members

Heat Transfer Division Committee rosters and contact information is available at:
<http://divisions.asme.org/htd/committees/index.html>

Newsletter Contact

Please send heat transfer related news items and brief articles to the editor:
P.D. Jones, pjones@eng.auburn.edu

Upcoming Conferences

Notice of conferences of interest to HTD members are posted on the web at:
<http://calendar.asme.org/home.cfm?EventTypeID=1>

ADDITIONAL UPCOMING CONFERENCES ARE:

2007 AJTEC/InterPack, July 2007, Vancouver, BC, contact Rod Douglass
<http://www.heattransferconference.org>

2010 International Heat Transfer Conference, Washington, DC, contact
Yogesh Jaluria

Treasurer's Report

The division's custodial balance has continuously increased from \$21,460 in 2003, \$51,875 in 2004, \$63,612 in 2005 and \$86,697 in January 2006. The division's incomes are contributed from conference/exhibit revenue, income from investment such as unrealized capital gain/loss, and miscellaneous revenue such as periodic interest distribution. The custodial balance gains in 2005 and January 2006 are largely contributed from successful conferences of the 2005 Summer Heat Transfer/Interpack Conference in San Francisco and 2004 IMECE in Anaheim. The conference/exhibit revenue transfer to the division custodian fund is the largest contribution to the HTD ending balance. The major expenses are food & beverages, reproduction, and awards & honorariums. The Executive Committee has discussed how to use the increased custodian funds for division members in the 2005 IMECE EC meeting.

Chang Oh,
Treasurer 2005-2006

State of the Journal of Heat Transfer

The *Journal of Heat Transfer* has grown substantially in recent years, both in terms of the number of papers published and the impact on the field. Many substantial improvements have been made in the journal, including increasing the frequency from bi-monthly to monthly and bringing out special issues on important areas of heat transfer. It has become one of the preeminent avenues for the dissemination of research results in heat transfer and serves as a dominant source of archival information for academia, industry, national labs and other organizations. However, the scope and impact of the field of heat transfer has also changed and grown over the past two decades. Since heat transfer is concerned with the transport of thermal energy, the field is intimately coupled with a wide variety of problems and systems. These include problems arising in diverse areas such as energy, environment, transportation, space, electronics, manufacturing, refrigeration and air-

conditioning, biological systems, security and, of course, heat transfer equipment. Thus, heat transfer must be considered in its broader concept of thermal sciences and engineering. The journal welcomes papers in all such areas in which thermal energy transport is a major consideration. Obviously, specialized journals have been developed to present problems, analyses and solutions in different areas, such as polymer processing, crystal growth, combustion, engines, gas turbines, electronic packaging and solar energy. However, basic and long-range concerns with heat transfer are common to many of these problems and similar solution strategies may be adopted. The *Journal of Heat Transfer* could be the natural venue for publishing the relevant analysis, experimentation and results.

While maintaining the high quality and standards that the journal is known for, we are striving to expand its reach and impact. There is a strong international base of authors, readers, reviewers and Associate Editors, due to increasing international contributions, as research in thermal sciences and related areas continues to grow around the world. The participation of industry has increased somewhat in recent years, but clearly much more effort is needed to publish high quality, archival, material that would be of practical and engineering interest to non-academic researchers and engineers. Similarly, publication of relevant papers by industrial researchers through review articles or contributed papers will strengthen the coupling between academic research and industrial needs. Effort is underway to examine the best approach to the publication of papers in applied areas, through special volumes and, possibly, through a companion journal in the future. A subcommittee consisting of industry researchers and some Associate Editors is currently looking at the viability of such a companion journal and the appropriate format that may be adopted for dissemination of results and enhanced industrial participation.

Yogesh Jaluria,
Editor

Report of the K-2 Long Range Planning Committee

Future of the Heat Transfer Division?

Moving Forward into the Next Decade

Approximately 9 months ago, the Executive Committee of the Heat Transfer Division made the decision to begin looking at how the Division was structured, with a goal of being more responsive to the needs of our membership as well as establishing a clearer leadership role in the emerging technological areas of the 21st Century. One motivation was our need to cope with the broad reorganization of ASME that has been underway for the last several years. Rather than simply adapting to this new organization with our existing structure, which has not changed in a significant way in over 30 years, it was felt that the Division leadership should step back to see if there might be a better way of doing things. The K-2 Committee on Long Range Planning has been charged with carrying out this assessment.

Before determining where we should be moving, it is important to understand more clearly where we are. The Division boasts some 4000 ASME members who declare their primary affiliation to be the HTD, with another 4000 or so secondary affiliates. However, the Divisional activities are almost exclusively focused on our two technical conferences each year, for about 400 participants, the vast majority of which are academics. Through a series of meetings and open discussions at the Summer Heat Transfer Conference and the IMECE during 2005, we are beginning to paint the picture of what the Division does well and what some of the challenges are for the future, as we determine how we can better serve the broader membership of the Division and the field of heat transfer. This article does not attempt to provide

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the answers to how a future restructuring should look. However, it may provide some level of foundation for moving forward. It represents largely the observations of the K-2 Committee Chair, with advice and consent of K-2 members and members of the HTD Executive Committee.

What We Do Well

It is crucial that any organizational change reflect both our strengths and the challenges that we face. The Division has long been recognized for the high quality technical sessions that comprise our conferences. These are principally the Summer Heat Transfer Conference and the IMECE. However, involvement in the Japan-US Heat Transfer Conferences, the AIAA Thermophysics Conferences, and the International Heat Transfer Conference also demonstrates our ability to provide a forum for discussion of fundamental heat transfer research that is at the forefront. These conferences provide outstanding opportunities for professional development of heat transfer researchers and for networking within the Division. The K-Committee structure through which technical sessions are organized has always been very inclusive. Young engineering faculty and others new to the Division, including graduate students, have a very easy time becoming fully involved, with the principal constraint being how rapidly a hand can be raised. Our conferences also maintain a close connection with the *ASME Journal of Heat Transfer*, arguably the strongest journal in the field, and certainly one of the most financially successful.

Challenges to the Division

There are a number of areas of concern that should be a central feature of any changes in the organization of the Division that may be implemented. We need to increase the relevance and impact of heat transfer research and to demonstrate the impact outside the close quarters of our conferences. A related and longstanding problem is the limited participation in HTD activities by industry,

despite the fact that over 70% of HTD members are non-academics. We have discussed this problem for as long as I can remember, but usually within the context of getting "them" to join "us" in our conference activities. Perhaps it is time for "we" to provide the type of experience that might be more valuable to "them".

There may be a need to interact more productively with the growing number of topical conferences. Although there are some problem areas where the heat transfer conferences provide the principal focus for research, specialized gatherings reveal the important multidisciplinary nature of most modern research problems. This is an issue that we struggle to deal with when the point of focus is heat transfer, rather than the technological problem requiring heat transfer research. Non-regulars may see a fragmented view of where the field is with respect to a particular technological area, because what is presented is an incremental piece of one aspect (the heat transfer aspect) of a multifaceted problem.

The current review system for heat transfer conferences is burdensome and in many cases ineffective. There is not a consistent approach to paper review across all technical sessions, with some reviews being conducted with as much rigor as the *Journal* and others being cursorily done by the session organizer. Given that the acceptance rate of papers at the two major conferences is well into the 90% range, we must ask ourselves whether the valuable time of the review community is being well used.

Our conference structure does not lend itself to effective networking outside the Division, even at the IMECE, where most of the ASME divisions are represented. For example, the K-17 Bioengineering Heat Transfer Committee has largely separated from the HTD and begun to work more closely within the Bioengineering Division. For many years, the Gas Turbine Heat Transfer group (K-14) has participated more directly in Gas Turbine Division activities.

Issues Related to the Current K-Committee Structure

Although the Divisional organization is the principal theme of our self-assessment, it is not clear that the current K-committee structure is the source of these challenges. Furthermore, growth of the Division, per se, should not necessarily be a major goal. However, broader participation of those who have already declared Heat Transfer as their primary affiliation and more effective service to them should be our goal.

The technical committee structure (most of the K-committees) certainly goes back 40 years or more and has often been cited as a strength of the Division. Some are quite new (Education, Visualization, Computation) and some are very mature (Low Temperature, Aerospace, Environment). They represent different types of constituencies and technological connections. K-17 Bioengineering Heat Transfer is moving more actively into the Bioengineering Division, while K-15 Transport Phenomena in Manufacturing and Materials Processing has virtually no connections to the Manufacturing Engineering Division. Some committees have a fundamental focus (Heat Transfer Fundamentals, Computation), while others tend to be very applied in their focus (Heat Transfer Equipment; Electronics).

A strength of this structure, a welcoming and inclusive environment, is also a weakness, in that membership can be quite loose. A goal of a new member may be more participation in Division activities rather than contribution to the mission of a particular committee, with one result that missions and related activities become rather ill-defined at times.

Our structure may serve as a hindrance to adaptation of the focus of the Division to emerging and developing technologies. Sessions on micro- and nano-scale thermal transport arise from perhaps half of our committees simultaneously. The result is sometimes a lack of cohe-

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Report of the K-2 Long Range Planning Committee

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siveness within sessions, as well as overlap among sessions, with occasional ludicrous results, such as different committees sponsoring sessions with the identical title at the same time in a conference.

Industrial Participation and “Applied” Research

A quick response to the “industry problem” may be to develop more applied technical sessions at conferences, with the hope that these might appeal to a broader audience. However, there is a serious danger in moving away from what we have been able to do very well—namely, to provide a technical forum for leading edge research. This is a key service to the academic sector. Experiences of this group with conferences that are very applications oriented are seldom very positive. Furthermore, it is not clear that people from the industrial sector are clamoring to come to HTD activities. This is especially true of the summer Heat Transfer Conference and events like the International Heat Transfer Conference, but perhaps less true for the IMECE, which may be the forum at which the HTD should seek a broader audience. Here are a few ideas that have been tossed around:

- Connect better to multiple disciplines within Mechanical Engineering at the IMECE each year. This might require a little effort to avoid duplicating the atmosphere of the fundamental summer conferences during the Heat Transfer Division portion of the IMECE.
- Establish more active participation in the multidisciplinary industry tracks that have been established at the IMECE each year.
- Exploit strategic co-locations with other groups more effectively at summer conferences.

- Seek out mutual representation at and by topical conferences, especially those that draw a multidisciplinary audience.
- At HTD events, utilize carefully planned “challenges and opportunities” sessions more frequently.
- Use tutorial sessions and short courses more effectively where an industrially based audience might be attracted.

Tied to these ideas of how HTD conferences can be made more broadly appealing is the basic structure of our conferences, although this is one small piece of a very complex problem. It may be necessary to do a more effective job of coordinating conference activities across the Division. This could lead to better inter-divisional planning, especially at the IMECE. A seemingly never-ending discussion at our conferences is the format for paper and presentation submission. However, the idea of “no review” conferences, once considered a taboo within any ASME conference, should probably be considered.

Plan of Attack

The paragraphs above lay out some of the strengths and weaknesses of HTD activities. To move more effectively toward a comprehensive self-examination, which might lead to specific proposals for structural modification, we propose a number of steps that can be undertaken within the current K-committee functions, as well as by the Executive Committee. K-2 will begin this process through the spring, with coordination of a series of steps that we hope will be accomplished by the various groups through the current calendar year. Unfortunately, the lack of a “normal” summer heat transfer conference will be a limitation to what might be

accomplished, so that some of these steps will need to take place asynchronously.

- The Executive Committee should review and re-write the HTD Mission Statement, better to reflect goals of more effective service to the field and to the broader membership of the Division.
- Each K-Committee should establish a clear mission statement. Such statements should be related to objectives and constituencies that the respective committees would want to serve. We need to establish clear assessment mechanisms that will allow us to evaluate how well we are meeting these objectives.
- It would be useful for each committee to develop a summary of recent technical sessions sponsored at meetings in a way that helps to identify important collective impact.
- Each committee should also identify important technological developments that can be embraced through its activities. This will help the Division membership to establish HEAT TRANSFER in a leadership position among the many multidisciplinary contributors to these emerging areas.

We will be approaching the Chairs of the various K-Committees with a charge to begin addressing these issues. The Heat Transfer Division can only move forward with the collective wisdom and effort of the membership and a commitment to embrace changes that will benefit us all.

*R. Smith,
K-2 Chair*

Fuel Cell Technology— A Myth or Reality?

A fuel cell is an electrochemical energy conversion device which converts chemical energy of a fuel into electrical energy, and heat and water are byproducts for hydrogen-oxygen (air) fuel cells. There is no combustion in this process. The fuel cell can produce electricity on demand continuously as long as fuel and oxidant are supplied, while disposable and rechargeable batteries have a limited life. Basically, a fuel cell consists of an anode, cathode, electrolyte/membrane and catalysts depending on the type of the fuel cell. Many different types of fuel cell are being developed currently, the most common being hydrogen-oxygen (air) based: Proton Exchange Membrane Fuel Cell (PEMFC); Phosphoric Acid Fuel Cell (PAFC); Molten Carbonate Fuel Cell (MCFC); Solid Oxide Fuel Cell (SOFC); Alkaline Fuel Cell (AFC); and Direct Methanol Fuel Cell (DMFC - the only one to use a liquid fuel, methanol). There are many other fuel cells being developed and invented. One common application that most are familiar with is the breath analyzer (ethanol-air fuel cell) that the police use to determine the alcohol content in the blood stream of motorists. Except for the DMFC, the typical power conversion efficiency of these fuel cells currently varies in the range of 30-35% and can reach 50-55% with a combined cycle or cogeneration for high temperature fuel cells.

Presently, all hydrogen-air based fuel cells together encompass the power generation range from about 1 W to several MW, and cover the application range where currently lithium-ion batteries are used or where fossil fuels are used for power generation such as portable devices, power plants, propulsion, or auxiliary power. There is practically no pollution generated from a hydrogen-air fuel cell except for CO₂ if natural gas/fossil fuels are used as the fuel. The pollution comes from reforming fossil fuels to make hydrogen, resulting in much less pollution than the current use of fossil fuels, but again no SO_x and NO_x. Since there are no moving devices in a fuel cell, there is no noise pollution except for compressors/fans/blowers used in the fuel cell power plant for air/fuel flows. A typical MCFC having 175 fuel cells each with 1 m² surface area, operating at 0.7 V cell voltage and 0.4 A/cm² current density, will generate about 0.5 MW of electric power using natural gas with practically no pollution!

The first practical use of the fuel cells started with the Gemini space program in late 1950s. After the use of PEMFC (with unstable operation; Nafion had not yet been discovered) in the first space mission, AFC was substituted and has been continued until today for all space programs for electric power for the space vehicle and to generate drinking water for the astronauts.

PEMFC is being developed for automotive power generation since it operates at low temperatures (80°C) for fast start-up. However, the major focus is the development of another membrane to operate at about 130-140°C to maintain the stack cooling radiator size similar to that of the IC engine with the additional benefit of better cathode kinetics. Remarkable progress has been made in developing fuel cell vehicles in the last 10 years and many fuel cell cars and buses worldwide are gathering operating experience to refine these systems. However, the major current hurdles for technology introduction are: (1) there is no infrastruc-

ture available anywhere in the world for hydrogen fueling stations (cost about \$1 million/station) at every 25 miles or shorter distance; (2) in spite of the rapid progress, the fuel cell stack/engine for vehicles is several times more expensive than the current gasoline engines; and (3) the stack durability needs to be demonstrated for the desired life of the vehicle in all environmental operating conditions. It is anticipated that a reasonable number of fuel cell vehicles will be on the road in the USA and Japan with government subsidies by around 2015, once the hydrogen highways are developed for fueling the vehicles.

For stationary power applications, phosphoric acid fuel cells were first developed, and 300-400 units of up to 200 kW have been sold in the 1990s for premier clean power requirement applications. However, due to its high cost per kW compared to grid power, they are not cost competitive and business growth has not occurred as expected. MCFC operating at 600-650°C have been developed and are operational at about 30 sites around the world with modules ranging from 100 kW to 250 kW with a total of 10 MW power installed. The goals of about \$1000/kW installed cost and durability of 40,000 hours operation before maintenance have not yet been reached. Siemens-Westinghouse has developed an ingenious SOFC design operating at about 1000°C, but the cost is very high. The current efforts for SOFC are the development of a 5 kW Auxiliary Power Unit (APU) for vehicular and other applications. Remarkable progress has been made in the last few years, and the APU designs are continuously being refined to improve durability and cost. The APU will have a significant impact on fuel consumption and reducing pollution when used in trucks parked at night on highways.

On the portable power front, in spite of the lower performance and efficiency of the DMFC, this fuel cell is almost cost competitive today with lithium-ion and lithium sodium batteries while increasing the operational time 2-4 times in the same packaging. Researchers are working worldwide to reduce the methanol crossover problem from the anode to the cathode, and even with partial success, DMFC will be the preferred power source for portable devices such as laptops, cell phones and hundreds of portable devices. Fuel cell battery packs are anticipated to be commercialized within a year.

Hydrogen is the preferred fuel for mobile fuel cell applications. For stationary power generation, hydrogen can be used, but currently natural gas is the choice for MCFC as the cost effective fuel. For many portable applications, methanol is the preferred fuel as it is a liquid fuel, no reforming is required, and it has high energy density but a low power density. Hydrogen can be reformed from fossil fuels (e.g., natural gas, crude oil, coal), can be made from electrolysis of water from intermittent electricity generated from renewable energy sources (solar, hydro, wind, wave, geothermal), electricity from using nuclear energy, or can be derived from bio-fuels (biomass, wood and organic waste, biogas, landfill gas, pyrolysis gas, etc.) and chemical intermediates (methanol, ethanol, NH₃,...). Once these technologies are developed to generate hydrogen cost-effectively, hopefully

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Fuel Cell Technology—A Myth or Reality?

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within next 40-50 years, our dependence on the fossil fuels will be diminished before their supply dries out. Fuel cells will be the major power source then onwards.

In conclusion, phenomenal research and development has been accomplished for all types of fuel cells in the last decade, and many day-to-day applications will use fuel cells for electric power in the coming decade. Once the technology becomes a common place, hydrogen will be generated from many non-fossil fuels and primarily renewable energy sources, maintaining global CO₂ balance and independency of fossil fuels. Vehicle pollution in the cities and urban area will be almost gone. There will be a fuel cell unit, about the size of a washing machine, in almost every house in developed countries generating electricity for all house-hold needs, and also generating its own hydrogen by electrolyzing water at night to fill up the fuel tank in the car to be ready for the next day driving, a new world that we can just imagine today!

R. Shah

Combining Technology, Assessment, and Feedback to Improve Student Learning—An Approach to Better Teaching in Large Classes

Numerous teaching techniques have been shown to result in improvements in student learning and understanding when compared to the traditional lecture. Yet these methods are not widely used in engineering. Faculty decide on their teaching approach based almost exclusively on their own experience, which is a combination of the methods used when they were taught, their own learning experiences and preferences, their experiences as a teacher, and conversation with others. Although faculty care deeply about teaching, motivation and support for change to different approaches are difficult to come by.

At the University of Wisconsin-Madison, several faculty have been engaged in using technology, assessment, and feedback in varying degrees to improve instructional methods in the large undergraduate thermal sciences courses (thermodynamics, fluid mechanics, heat transfer). The use of technology is different from what is normally envisioned, such as distance learning or web-based instruction. At Wisconsin the courses remain conventional in terms of a regularly scheduled large class with an instructor and students. The technology used increases student interactions and class participation, facilitates continuous assessment of student learning, and allows dynamic modifications and updates to the presentation of material. The manner in which technology, assessment, and feedback are incorporated in the University of Wisconsin thermal sciences courses as described in the following sections.

Technology

Technology enables a “just-in-time” syllabus and daily learning objectives based on daily feedback from in-class

assessment (e.g. concept inventory questions). A course homepage on the web allows the syllabus to be changed for every class period, if desired. Learning objectives for each class period are developed and defined as part of the regular routine of preparation. The technology is practical and an updated syllabus with learning objectives is readily developed for every class.

Technology is also used to conduct in-class simulations and virtual experiments using material available via the web. With web-based information, students can visualize and experiment with the physics and engineering of a particular topic. Often a web-based presentation provides opportunities for student learning that cannot be duplicated in a laboratory as, for example, aerodynamically induced flutter on an airplane surface in flight. NASA and others provide numerous videos of real flight controls undergoing flutter. A large number of sources for virtual experiments in the thermal sciences have been collected.

Technology facilitates in-class assessment of student learning through the use of a personal response system. The technology provides two distinct advantages: first, students are assured of anonymity in their responses, and second, the automatic recording of student responses allows instant summarization for the students and convenient archiving for the instructor.

Assessment and Feedback

Assessment of student learning is incorporated into all aspects of the courses. At the start of the semester, concept inventories (described later) are administered to measure initial student understanding of the subject. Concept inventories are administered again at the end to assess how much the students have learned as a result of taking the course.

We have found that students are motivated to check their own understanding, particularly if this does not have an effect on their grade. Typically, after a question is posed in class and answered via the personal response system, the class is asked to discuss the problem in small (2 – 3 student) groups, and then to respond again. These peer-to-peer interactions are a natural aspect of self-assessment because, in answering the questions, students prepare themselves to discuss the issue with their peers.

Homework is collected and graded, but in addition to the normal calculation type problems, students are given reading assignments. This was motivated by focus group work with students that verified how little reading of a text actually occurred in a course. The reading assignments involve making notes, drawing figures and diagrams, and writing out the mathematics as if the students are preparing to teach the material to someone else. In order to make this something that students engage in with care it is necessary to make the reading assignments short, typically 4-6 pages.

Finally, examinations are also part of the assessment process. Examinations complement the “formative” evaluations and allow a “summative” assessment of student learning.

Student Response

A post course survey has been used to evaluate the effectiveness of these techniques on student learning,

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Combining Technology, Assessment, and Feedback to Improve Student Learning—An Approach to Better Teaching in Large Classes

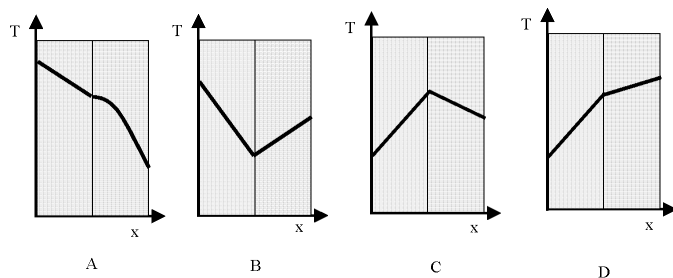
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retention of the material, and the influence of class size. Approximately half of the students felt that their study habits changed. They focused on concepts and not just problem solving and read the assigned material more carefully. Many students found that taking notes on the required readings and the concept questions in lecture were the most effective learning methods. All of the students felt they have some sort of a conceptual framework in the subject. A little over half did not feel that class size affected their learning. The other half perceived the class (which was really 50) to be only 25 – 35 students, and they then felt that the “small” class size allowed for good discussion and made it easier to ask questions.

Concept Inventories

A concept inventory is a set of questions (typically about 30) that evaluates the understanding a student has of a concept rather than whether the student can solve a particular problem. A typical heat transfer concept question is given below:

“The composite wall shown below is composed of two layers, each with constant properties. For steady state conduction through the wall with no internal generation of thermal energy, circle the letter of the temperature distribution that is possible:”



A set of concept inventories have been developed for the thermal sciences and are available on the Concept Inventory Website for use. These inventories are being used to assess the student understanding at the beginning and end of a semester. The pre- and post-test scores for three classes of 40 to 50 students are given in the table below.

Class	Pre-test	Post-test	Gain
Thermodynamics	56 %	64 %	8 %
Fluid Mechanics	40 %	55 %	15 %
Heat Transfer	36 %	57 %	21 %

The pre-test scores are relatively high in thermodynamics, which demonstrates that students typically enter with a fairly high level of conceptual understanding of the material. The pre-test scores decrease through the sequence as the material becomes increasingly specialized and technical.

There was roughly a two-to-one range in the pre-test scores of individual students. The wide variation in student understanding coming into a course can be expected to impact individual understanding to varying degrees.

The gains are not high, and we are experimenting with methods to increase them. The final post-test scores are essentially the same. Apparently, the average student leaves each of the thermal science courses with about the same level of conceptual understanding.

For the heat transfer concept inventory, the highest score was 81 % and the lowest 18 %, indicating a four-to-one range in understanding. There were several scores of 75 % and above, while only a few scores were below 25 %. Since all of the students had passed the course based on the traditional methods of grading (problem-solving examinations and homework), this suggests that conceptual understanding is not a necessary prerequisite for problem solving mastery.

There was some correlation of the gains with topic, as shown for each of the three traditional heat transfer subjects in the table below.

Subject	Post-test score	Gain
Conduction	68 %	22 %
Convection	56 %	17 %
Radiation	29 %	8 %

The scores are what we might expect. Traditionally, conduction is the first subject taught, and is generally thought to be easiest conceptually and mathematically. Convection, combining conduction and fluids, is more difficult. In radiation the concepts are new, there is very little carryover from conduction or convection, and significantly less time is spent on the material. Students have had little every day experience with radiation and are often confused about the mechanism and the mathematics.

Conclusion

New methods of instruction can be used to help students learn better, and these techniques are especially useful for larger class sizes. The University of Wisconsin faculty who are developing new methods (J. Martin, F. Pfefferkorn, S. Sanders, T. Shedd) would be pleased to share their experiences. The Concept Inventories for the Thermal Stem, developed in conjunction with T. Newell and A. Jacobi of the University of Illinois, are available on the University of Wisconsin College of Engineering Website. The authors would be delighted to have you use the inventories, and only request that you send them the results for your classes.

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Concept Inventory Website:

<http://www.engr.wisc.edu/> > Course HomePages > Mechanical Engineering > ME 363 Fluid Dynamics > Course Homepage of Professor Martin > Concept Inventories and Information on Concept-Based Instruction > Concept Inventories.

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