Development of a Heat Transfer Module for Design Courses

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Abstract
Due to time constraints and the lack of available educational materials, students in engineering and engineering technology often do not get an opportunity to work actual design problems in heat transfer. This is especially true for those students taking concentrations in machine design and manufacturing. Upon graduation they are frequently faced with heat transfer issues, where they must find usable data and make educated decisions.

Capstone or design project courses frequently offer an opportunity to expose the student to applied heat transfer design problems. This paper describes the development and testing of a module that may be plugged into a design or project course to expose students to practical heat transfer design. Module elements include a review of heat transfer modes and mathematical models, as well as lecture and lab elements targeted toward problems frequently encountered in manufacturing processes.

Introduction
Most introductory courses in heat transfer have similar formats that provide an introduction to the basic theory of the various modes of heat transfer. Some courses even include supporting laboratory experiments that demonstrate and reinforce one or more of the basic concepts. However, in the authors' experience, the typical undergraduate engineering or engineering technology curriculum does not include an advanced or applied heat transfer course, and design project or capstone courses are often aimed at other disciplines such as manufacturing or machine design. Therefore, many students never have an opportunity to apply the basic heat transfer principles learned in introductory courses to more complex, realistic design problems. A search of recent developments in heat transfer education produced studies dealing with very specific areas such as improved heat transfer experiments, software- or web-based materials, and team-based learning, but no prior work was found using a comprehensive design-focused approach[1-5].

To address this need, an applications-oriented heat transfer instructional module was developed for use in design project or capstone courses. The module includes both a review of basic heat transfer concepts and an introduction to their applications in design-type situations. The module described in this paper specifically targets a senior design course in plastics manufacturing in a mechanical engineering technology curriculum, but the basic structure is such that it can be easily adapted for other capstone courses. The following discussion presents the development of the module itself as well as results from its recent implementation in the classroom.

Module Development
Development of the instructional module began with reviewing the material currently covered in the required introductory thermal science course in the Mechanical Engineering Technology (MET) curriculum at Purdue University, as well as in other introductory heat transfer texts[6]. In

the introductory course, topics covered include steady and transient heat transfer, with emphasis on conduction and convection modes. Radiation heat transfer is introduced but not covered in any depth. These concepts are delivered over a period of about six weeks, which is a portion of a combined thermodynamics and heat transfer course.

For a capstone course, it was desired to limit the heat transfer module to approximately 4-5 lectures and 1-2 laboratory experiments, allowing enough time for reviewing basic concepts and introducing sufficient new material specific to applications in plastics manufacturing. Table 1 compares the basic structure and topical coverage of both the introductory course and the heat transfer module.

Table 1. Comparison of heat transfer module and introductory course topics.

INTRODUCTORY COURSE	HEAT TRANSFER MODULE
Introduction to Heat Transfer • Basic Concepts o Conduction Heat Transfer ▪ Definition ▪ Model ▪ Properties o Convection Heat Transfer ▪ Definition ▪ Model ▪ Coefficients o Radiation Heat Transfer ▪ Definition ▪ Model	**Introduction to Heat Transfer** • Basic Concepts o Conduction Heat Transfer ▪ Definition ▪ Model ▪ Properties • Thermal conductivity of metals • Thermal conductivity of insulation • Thermal conductivity of plastics o Convection Heat Transfer ▪ Definition ▪ Model ▪ Coefficients • Coefficients for air cooling • Coefficients for water baths o Radiation Heat Transfer ▪ Definition ▪ Model
Heat Transfer Analysis • Steady Heat Transfer o Plane Wall Systems o Cylindrical Systems • Transient Heat Transfer o Lumped Systems	**Heat Transfer Analysis** • Steady Heat Transfer o Plane Wall Systems o Cylindrical Systems ▪ Example: Pipe System • Transient Heat Transfer o Lumped Systems o 1D Systems ▪ Example: Cooling Plastic in Mold ▪ Example: Cooling Extruded Part

The main difference between the heat transfer module and the material covered in the introductory course is that thermal data and example problems in the module are geared toward a specific heat transfer application, in this case plastics manufacturing. Thermal property values and coefficients are given for materials generally found in plastics manufacturing systems. An example is shown in Figure 1 below. In addition, example problems used throughout the module are related to applications within the plastics manufacturing field. Using discipline-specific properties and examples are the basic modifications necessary for adapting the module to other courses.

Polymer	Thermal conductivity λ[W/m·K]	Specific heat c_p[kJ/kg K]	Density ϱ[g/cm^3]	Glass transition temperature T_g[°C]	Melting point range T_m[°C]
PS	0.12	1.20	1.06	101	–
PVC	0.21	1.10	1.40	80	–
PMMA	0.20	1.45	1.18	105	–
SAN	0.12	1.40	1.08	115	–
ABS	0.25	1.40	1.02	115	–
PC	0.19	1.40	1.20	150	–
PE-LD	0.24	2.30	0.92	−120/−90	ca. 110
PE-LLD	0.24	2.30	0.92	−120/−90	ca. 125
PE-HD	0.25	2.25	0.95	−120/−90	ca. 130
PP	0.15	2.10	0.91	− 10	160–170
PA-6	0.25	2.15	1.13	50	215–225
PA-6.6	0.24	2.15	1.14	55	250–260
PET	0.29	1.55	1.35	70	250–260
PBT	0.21	1.25	1.35	45	ca. 220

Figure 1. Thermal data for commonly used polymers.[7]

One issue encountered during the module development was the lack of consistent heat transfer terminology. Heat transfer texts and references do not use a standard set of terminology and symbols in the presentation of basic concepts. To maintain consistency within the degree program, all symbols used for the basic concepts and equations in the module were the same as those used in the introductory course.

This problem raised an opportunity to expose students to a common roadblock. In the practice of engineering, data may be obtained from many sources, and the ability to comprehend and combine data in different unit systems, with different variable names, and from different references is important. Typical heat transfer textbooks do not include data related to many specific industrial applications such as plastics manufacturing. To expose students to information that is applicable to realistic situations, it was necessary to consult other handbooks and resources. For this module, which focused on applications in plastics manufacturing, data was extracted from both printed material and resin manufacturers' web sites. Differences between these sources and the introductory material were then identified to the students.

Results

In the Fall Semester of 2002 the heat transfer module was successfully employed in a senior design course in the MET curriculum at Purdue University. This course, Plastics Manufacturing Systems (MET 490), is a capstone-type course for students interested in machine design and manufacturing. It focuses on the design of plastics manufacturing equipment. Since most plastics manufacturing processes contain some thermal control, this course was a good test bed for the heat transfer module.

In order to provide a baseline for assessment of the module, some questions were posed to students in the first class period. These were:

1. *If oil is flowing through a heated pipe, what is (are) the heat transfer mode(s) by which heat is transferred to the oil?*

2. *In the question above, what factors influence the temperature of the oil at any given point along the pipe?*

Since all of the students had taken a required course in thermal sciences, Question 1 was designed to check their retention and understanding of the basic concepts of heat transfer. Question 2 was aimed at assessing their ability to apply the basic concepts in order to understand the important influences in a design problem. Table 2 below lists the answers given to these pre-test questions.

Table 2. Student responses to pre-test questions.

Question 1: If oil is flowing through a heated pipe, what is (are) the heat transfer mode(s) by which heat is transferred to the oil?
• Heating element & friction
• Convection
• Blank
• Blank
• Conduction, convection, & radiation – Heat is transferred to the oil by conduction
• Blank
• Conduction
• Blank
• Blank
• Friction and the transfer of heat from the pipe to the oil
Question 2: In the question above, what factors influence the temperature of the oil at any given point along the pipe?
• Viscosity
• Flow, pressure
• Length of pipe, insulation
• Velocity, viscosity of the fluid, density of the fluid
• Friction within the oil & between the oil & pipe, laminar and turbulent flow
• Pipe temperature and flow speed
• Velocity, mass flow
• Blank
• Blank
• Temp of the pipe, velocity, time it has been in the pipe, density and other physical properties of oil

Fifty percent of the students left Question 1 blank, and none of the rest gave answers that were completely correct. It is interesting that fewer students left Question 2 blank than did Question 1. Again, few students answered the question completely and correctly.

The module was then presented in four 50-minute lecture periods. The first period was spent reviewing the basics of heat transfer. In the second period some problem solving strategies for steady state heat transfer problems were discussed and a problem involving heat transfer in a pipe system was solved. In the third lecture transient heat transfer was discussed and a conduction problem, cooling of molten plastic in a mold, was solved. The last lecture was devoted to multi-mode transient heat transfer with conduction and convection. Throughout the module emphasis was placed on providing practical solutions to problems. These problems were limited in scope to common problems encountered in plastics processing, such as cooling time for molded plastics and cooling of extruded plastics.

An exam was given following the presentation of this module and one problem was directed at the students' ability to apply the module concepts to a realistic problem. The question was as follows:

A rectangular shaped part, 6" x 4" x 1/8" thick is injection molded from general purpose grade of LEXAN® (121 series). Estimate the demold time for the part. Document any assumptions you have to make. [Hint: $a = k / (\rho\ cP)$, 1 lb = .454 kg, 1 BTU = 1055 W sec]

Students were given a copy of the polymer data sheet for the LEXAN® 121 material, which was downloaded from the General Electric Plastics web site. Figure 2 below and Figure 3 on the following page show the web site interface and the LEXAN® 121 data sheet, respectively.

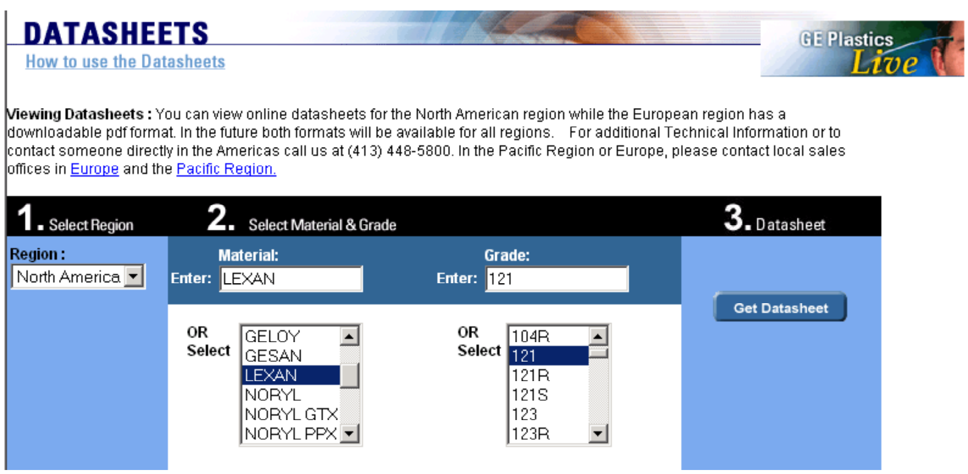

Figure 2. Access to the LEXAN® 121 data sheet from the GE Plastics web site.[8]

Of nine students taking this exam, 7 correctly solved the problem. Of the two who solved it incorrectly, one student assumed a convection component to the problem while another student did not correctly set up the problem. This represented a great improvement over the response to the pre-test questions asked at the beginning of the semester. The module improved the students' ability to understand the basic concepts involved in the problem, use the commercial data sheet to extract the relevant information, and apply the appropriate analysis method to solve the problem. In addition, students later applied the module tools in the planning of their capstone projects, when they were required to estimate cycle times for temperature control circuits.

THERMAL			
Property	**Typical Data**	**Unit**	**Method**
Vicat Softening Temp, Rate B	310	deg F	ASTM D 1525
HDT, 66 psi, 0.250", unannealed	280	deg F	ASTM D 648
HDT, 264 psi, 0.250", unannealed	265	deg F	ASTM D 648
CTE, flow, -40F to 200F	3.8 E-5	1/F	ASTM E 831
Specific Heat	0.30	BTU/lb-F	ASTM C 351
Thermal Conductivity	0.25	W/m-C	ASTM C 177
Relative Temp Index, Elec	130	deg C	UL 746B
Relative Temp Index, Mech w/impact	130	deg C	UL 746B
Relative Temp Index, Mech w/o impact	130	deg C	UL 746B
PHYSICAL			
Property	**Typical Data**	**Unit**	**Method**
Specific Gravity, solid	1.20	-	ASTM D 792
Specific Volume	23.10	in3/lb	ASTM D 792
Density	0.043	lb/in3	ASTM D 792
Water Absorption, 24 hours @ 73F	0.150	%	ASTM D 570
Water Absorption, equilibrium, 73F	0.35	%	ASTM D 570
Water Absorption, equilibrium, 212F	0.58	%	ASTM D 570
Mold Shrinkage, flow, 0.125"	5-7	in/in E-3	ASTM D 955
Melt Flow Rate, 300C/1.2 kgf (O)	17.5	g/10 min	ASTM D 1238

Processing

INJECTION MOULDING-USA		
LEX-IM-06		
Drying Temperature	250	deg F
Drying Time (basic)	3-4	h
Drying Time (cumulative)	48	h
Moisture Content, max	0.02	%
Moisture Content, min	-	%
Melt Temperature	540-580	deg F
Nozzle Temperature	530-570	deg F
Front Temperature	540-580	deg F
Middle Temperature	520-560	deg F
Rear Temperature	500-540	deg F
Mold Temperature	160-200	deg F
Back Pressure	50-100	psi
Screw Speed	40-70	rpm
Suggested shot size	40-60	%
Clamp Tonnage	3-5	tons/psi
Vent Depth	0.0010-0.0030	inch

Figure 3. LEXAN® 121 data sheet given to students.[8]

Future Development

In the Spring 2003 semester at Purdue, the heat transfer module will be incorporated into another class, Advanced Manufacturing Processes (CIMT 342), part of the Computer Integrated Manufacturing Technology (CIMT) program. This class is centered on manufacturing process design and analysis. The students in this class will not have taken any thermal science courses prior to exposure to the heat transfer module. Therefore, more emphasis will be put on the first portion of the module to give the students a background before tackling problems.

Development of laboratory experiment(s) to demonstrate heat transfer principles and practical examples was delayed due to funding and time available. This did not significantly affect the machine design class as their projects incorporated temperature control circuits, but supporting lab exercises will be helpful in the future for continued improvement of the module.

Conclusions

The implementation of the heat transfer instructional module was successful in providing realistic heat transfer design exposure to students in the plastics manufacturing course. Testing before and after the presentation of the module indicated a significant increase in understanding of the basic concepts by the students, and an improvement in their ability to use commercial data and analyze realistic problems in plastics manufacturing. Additionally, students applied the module concepts further in the planning of their capstone projects. The heat transfer module is flexible, allowing for adaptation to other disciplines with application-specific modifications in the areas of property data and example problems.

References

[1] Kaminski, W.R., (1998), A series of heat transfer experiments for the mechanical engineering technology student. *Proceedings of the 1998 American Society for Engineering Education Annual Conference & Exposition* (CD-ROM), American Society for Engineering Education.

[2] Somerton, C.W., Elliott, G., Vance, R., (1999), Incorporating the design of experiments into a heat transfer laboratory course. *Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition* (CD-ROM), American Society for Engineering Education.

[3] Somerton, C.W., Smith, M., Lu, M., (2001), A MATLAB program for teaching convective heat transfer. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition* (CD-ROM), American Society for Engineering Education.

[4] Newell, T., Shedd, T., (2001), A team-oriented, project-based approach for undergraduate heat transfer instruction. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition* (CD-ROM), American Society for Engineering Education.

[5] Braga, W., (2002), Teaching strategies for undergraduate heat transfer courses. *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition* (CD-ROM), American Society for Engineering Education.

[6] Hagen, K.D., (1999), Heat Transfer with Applications, Upper Saddle River, NJ: Prentice-Hall.

[7] Rao, N., O'Brien, K., (1998), Design Data for Plastics Engineers, Cincinnati, OH: Hanser/Gardner Publications.

[8] General Electric Plastics website (December 2002), http://www.geplastics.com

Biography

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