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# Using a MATLAB Exercise to Improve the Teaching and Learning of Heat Conduction During Welding*

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*This paper reports on an action research project to improve teaching and learning in a computer simulation of heat conduction during welding. The research was initiated, planned and carried out by Johan Ahlström, a lecturer in materials science at the Chalmers University of Technology, Sweden, in consultation with an educational developer, Michael Christie. The exercise on which this paper focuses is part of an optional Master of Science course that is offered to both Chalmers and international students. The exercise involves the modelling of heat conduction during welding. In the past the exercise involved the use of MATLAB. The use of MATLAB has posed some problems but after the course was opened up to overseas students these problems were compounded. The Swedish students had at least some basic knowledge of MATLAB but several of the foreign students have no experience at all of using the program. As a result a lot of time was given to helping students understand and use MATLAB even though the main purpose of the exercise was to help them come to grips with the actual problem of modelling and understanding heat conduction during welding. It was clear, from discussions between the two authors, that the original aim of the exercise was being subverted and that in pedagogical terms this affected the constructive alignment of teaching and learning. This paper reports on actions taken to resolve this dilemma and an evaluation of the success of the changes that were introduced. It also proposes a simple formula for curriculum reform that can be used to initiate and evaluate changes to existing exercises and courses in engineering education.*

## INTRODUCTION

FOR MANY YEARS, the Chalmers engineering course MMK210 Joining Technology has included an exercise to be solved using MATLAB. The task is part of the overall assessment of the course and corresponded to 0.5 credit units, where one unit equals a week's full time study. The examiner for the course is Professor Birger Karlsson but Johan Ahlström has been the supervisor for the exercise we are focussing on for a few years now. The course has been optional for mechanical engineering students in their fourth year, but from the spring of 2002, the course was also offered to the participants of the Master of Science program 'Advanced Materials' and to Erasmus students. This meant there has been an increased difference among the students regarding programming skills in MATLAB. The Swedish students have at least some basic knowledge whereas several of the foreign students have no experience at all of using the program. The spread of mathematical abilities among engineering students and the variation in their capacity to understand and use programs such as MATLAB has been referred to in a number of other studies [2, 7–9].

The physical phenomenon to be modelled concerns heat conduction during welding. Welding is a means of joining two pieces of metal by heating the interface above the melting temperature and letting the liquid metal solidify together, often with addition of material from a filler wire. The heat source used is moved along the so-called weld line. In the process, the material around the weld line is rapidly heated and cooled. The resulting mechanical properties of the material being welded often drastically depend on heating and cooling rates and maximum temperatures reached during welding. It is therefore important to understand temperature histories of each point along the weld line in order to judge resulting properties of the joined materials. The aim of the exercise is to gain increased understanding of how different combinations of welding parameters, as well as different material properties influence heat distribution and thus, the shape of the temperature peaks described above. From that, students should be able to draw conclusions about the consequent changes to the properties of the material for different locations around the weld line. Figure 1 gives an example of output from the MATLAB program. The height above the base plane as well as the colour tone (for printing reasons grayscale in this publication, otherwise normally in colour) depicts the temperature distribution.

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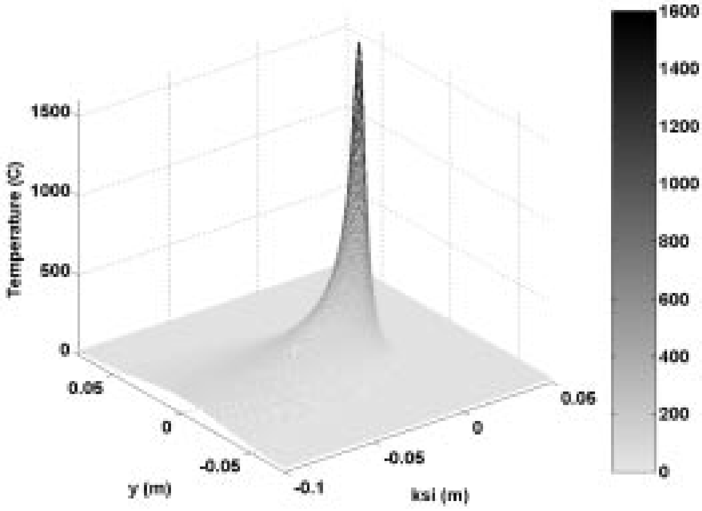


Fig. 1. Example of output from the MATLAB program: Temperature distribution around the moving heat source (located in the origin) moving in the positive ksi-direction.

## THE PEDAGOGICAL PROBLEM

From interaction with students during 'consultation times' and from studies of reports and evaluations from earlier years, it was observed that for many students the MATLAB programming took so much time and effort that the opportunity and motivation to understand and treat the actual topic was diminished. Even the Swedish students from the mechanical engineering programme experienced this pressure. The output of the modelling, mainly in the form of graphs, often resulted in a format that made them useless for judging and comparing calculations for different parameter combinations. The reports were often bad and in many cases excluded the last and most important analyses of the physical phenomena. We decided to carry out a small piece of action research in an effort to improve matters. The co-author of this paper was already engaged on a project aimed at enhancing the constructive alignment of coursework at Chalmers that was funded by the Chalmers Strategic Effort on Learning and Teaching (hereafter C-SELT) and the reform of this exercise fitted naturally into it.

John Biggs [1] in his book on *Teaching for Quality Learning in Higher Education* talks about the 'constructive alignment' of teaching and learning. He is credited with the phrase but both the concept and the process have been around for a long time. The label has two parts. The 'constructive' part refers to the type of teaching and learning that is favoured. The idea that 'We learn best by doing' is an integral part of John Dewey's educational theories. He argues in his classic text, *Democracy and Education* (1916), that 'there is no such thing as genuine knowledge and fruitful understanding except as the offspring of *doing*' [3]. Others, who call themselves 'constructivists', have built a theory based on this axiom [5]. In teaching circles constructivists argue that learning is most effective when we are lead to discover knowledge ourselves. The exercise on heat conduction during welding was a good example of this. The students discover for themselves the influence of different heat parameters on the properties of materials during welding. Our interest in this type of experiential learning [6] is based on a conviction that learning is more likely to be internalised and therefore easier to apply. The second part of the label refers to linking or aligning the learning objectives, the teaching methods and the assessment of an educational course or programme. We refer to learning outcomes below. The learning method we chose was pair work. Given the limited time available we saw this as the most effective way of promoting discussion and teamwork while at the same time maintaining a sharp focus on the problem solving. Each pair was asked to submit a report in which they explained their results and the process used to obtain them. They were also asked to submit their printouts which could be checked for technical and other errors. On the basis of the reports the teacher was able to determine if the students actually understood heat conduction during welding and the effects of temperature history on the properties of the materials being welded.

## THE ACTION RESEARCH PROJECT

The action research we carried out was based on a set of questions that acted as a simple model or checklist. We asked ourselves the following: What is the purpose of this piece of action research? How can we best achieve our purpose? How will we know if we have achieved our purpose? How can we improve on any achievements we make? We decided our aim was to investigate, develop and implement an alternative way of teaching the exercise so that we improved the constructive alignment of the exercise, facilitated learning about heat conduction and gave the students a deeper understanding of the physical problems involved in welding. Our first step was to introduce a pre-written MATLAB programme (see Appendix 1), have some of the students use it and to try to evaluate the impact on their learning compared with others who had not been exposed to this change in the exercise. The idea was to change the focus of the exercise from 'MATLAB programming applied to welding' to 'understanding welding using MATLAB'

To be able to judge the outcome of this pedagogical experiment a control group was used. The class was divided into two groups, A and B. The students belonging to group A were paired off and asked to write the MATLAB program themselves (similar to earlier years) while group B students were given a pre-written program. As the group B students had been relieved of the workload involved in writing the MATLAB program, they were asked to study twice as many parameter combinations (16 instead of 8). Two different pro memoria (PMs) describing the tasks for groups A and B were prepared. The class consisted of 12 M4 students, 9 Master's students, 6 Erasmus students and 2 Ph.D. students. The division was done randomly within each category of students, i.e. with half of the M4 students belonging to group A and B respectively and similar for the other categories. An evaluation form for judging the outcome of the experiment was prepared. In formulating this form we made use of ideas from George and Cowan [4]. The survey consisted of a general part, where the student's views on learning, etc., were asked for, and one technical part which tested the students' level of understanding of the topic (see Appendix 2).

The heat conduction exercise was introduced in class at an announced time (normal lecture time, given in the PMs for the whole course). The students were informed that they were going to be divided into two groups, which were to be given different tasks and that this was a pedagogical experiment. Within the two main groups the students were asked to form sub-groups consisting of two persons. The PM's were distributed and the tasks were explained further. One week later, there was one full day reserved for consultation, and almost two weeks after distribution of the tasks, the reports were due. These were submitted during one of the scheduled lecture times for the course. At the same time students were asked to fill in the evaluation form. It was pointed out that this was not compulsory. Further, the students were assured the forms would not be read until the reports were graded. The reports were corrected and graded from 3 to 6. A three was required for the report to be accepted. A six was the highest grade possible. Reports which were not acceptable were returned with advice for improvement and if this was done properly these were given grade 3. The evaluation forms were analysed in the following order: first the technical questions were scored without looking at group participation and after that, the general questions were summarized.

## RESULTS

Our first observation was that there was a considerable difference in the students' need for consultation time. The students belonging to group A needed approximately 5 hours supervision, while the group B students used less than 1 hour. During marking of the reports, some similarities were found between the prepared program and the programs developed by the group A students. Co-operation between the different subgroups was expected, and the similarities were not larger than we deemed acceptable. If the quality of the reports is compared, it can be seen in Tables 1 and 2 for group A and B respectively that the differences between the two groups were relatively small. If the two groups whose reports were not accepted in the first run are disregarded, we have an average of 4.3 for group A compared to an average of 4.8 in group B. However, this judgement could include some subjectivity as we did not want to create large differences in grades between the two groups, especially since the quality of the graphs that resulted from the prepared program were due to our own programming and not that of the students. It would, for example, have been unfair to expect the same quality of graphs from the students in group A. Unfortunately pedagogical experiments cannot be conducted in the same rigorous way as scientific experiments where variables can be more easily controlled. Our intention was to test the usefulness of a prepared MATLAB application in encouraging a sharper focus on and a deeper understanding of the topic itself.

The next thing to be compared in Tables 1 and 2 is the results of answers to the technical questions. The first number shows the score for the first four questions (4 was maximum) while the second number shows the total score for all six questions (6 was full-score). The reason for this distinction is that the two last questions concerns variation of a parameter that was studied only by group B students. Here the differences between the two groups are larger, Group A students had averages of 2.5 and 3.3 while group B students got 3.2 and 4.7 respectively. In these calculations we have excluded two pairs. One pair was from group A. They did not answer the required questions due to 'lack of time' and were failed. From discussions with them however it is clear that they would have achieved very low scores. To equalise matters between the two groups we also excluded a pair from group B who had been asked to re-submit their report. If the latter pair had been included, the mean values for group B are 2.8 and 4.1 respectively.

If the students' opinions on group membership are evaluated, there are of course large differences

Table 1. Results of the report grading and evaluation form for group A. The abbreviation 'h.c.' stands for heat conduction and the sign '—' means 'no information'. The number within parentheses in the column for time spent is the time needed for programming. The mean values calculated at the end include only information from non-shaded fields.

| Sub-group | Report grade | Category | Techn. questions | | Happy in group? | Time spent (h) | MATLAB experience/ Learnt MATLAB? |
|---|---|---|---|---|---|---|---|
| A1 | 5 | M4 | 2.5 | 3.5 | No, learnt less h.c. | 10 (6) | Some/Yes |
| | | M4 | 3 | 4.5 | No, learnt less h.c. | 9 (6) | Good/Yes |
| A2 | 6 | Master | — | — | — | — | — |
| | | Master | 3 | 5 | Yes, want to learn MATLAB | 40 (16) | Medium/Yes |
| A3 | Returned | M4 | — | — | No, dislike programming | 7 (4) | Some/Little |
| | | M4 | — | — | No, dislike programming | 7 (4) | Medium/Little |
| A4 | 4 | Erasmus | 0 | 0 | Yes, learnt more | 12 (10) | Good/Yes |
| | | Erasmus | 3 | 3 | Yes | 12 (8) | None/Yes |
| A5 | 5 | Erasmus | 3.5 | 5 | Doesn't matter, learnt MATLAB! | 20 (15) | Some/Yes |
| | | Master | — | — | — | — | 'None' according to group mate |
| A6 | 3 | Master | 2 | 2 | Doesn't matter, learnt MATLAB! | 15 (9) | Some/Yes |
| | | Master | 1 | 1 | Doesn't matter | 15 (9) | Some/Yes |
| A7 | 3 | M4 | 3.5 | 3.5 | Yes, enjoy programming | 12 (7) | Good/Little |
| | | M4 | — | — | — | — | — |
| A8 | 4 | PhD | 3.5 | 5.5 | Doesn't matter | 50 (30) | None/Yes |
| *Mean* | *4.3* | *6 M4*<br>*5 Master*<br>*3 Erasm.*<br>*1 PhD* | *2.5* | *3.3* | *No: 4*<br>*Yes: 4*<br>*Doesn't matter: 4* | *20 (12)* | *None: 3*<br>*Some: 5*<br>*Medium: 2*<br>*Good: 3* |

among the individuals in the two groups; some of the group A students are positive about writing the code themselves as they learn MATLAB programming while others are negative to having to write the code themselves as this does not lead to increased understanding of the physical problem but instead decreases the time left for interpretation of results. Most of the group B students quote that they are happy in their group, or that it does not matter. The statement that it 'doesn't matter' is surprising in some cases—for example, group B7 used a lot of time for the task even though they had the benefit of the prepared program. Since they state that their MATLAB knowledge was limited the use of the prepared program should have saved time for them.

Table 2. Results of the report grading and evaluation form for group B. The sign '—' means 'no information'. The mean values calculated at the end include only information from non-shaded fields.

| Sub-group | Report grade | Category | Techn. questions | | Happy in group? | Time spent (h) | MATLAB experience/ Learnt MATLAB? |
|---|---|---|---|---|---|---|---|
| B1 | 5 | M4 | 4 | 6 | Doesn't matter | 8 | Good |
| | | M4 | — | — | — | — | — |
| B2 | 6 | Master* | 4 | 6 | Doesn't matter | 15 | Medium |
| | | Master | 4 | 6 | Doesn't.matter | 15 | Medium |
| B4 | 4 | Master* | 3.5 | 4.5 | Yes, no programming | 7 | Some |
| | | Erasmus | 1 | 2 | Yes, more interpretation | 10 | Some |
| B5 | 4 | PhD | 3.5 | 4.5 | Yes, no programming | 32 | None |
| | | M4 | 3 | 5 | No, less interpretation | 3 | Good |
| B6 | 5 | M4 | 2 | 3 | Yes | 12 | Good |
| | | Erasmus | 3.5 | 5.5 | Doesn't matter | 12 | Some |
| B7 | Returned | Master | 1 | 1 | Doesn't matter | 40 | None |
| | | Erasmus | 1 | 1 | Doesn't matter | 48 | Some |
| *Mean* | *4.8* | *4 M4*<br>*4 Master*<br>*3 Erasm.*<br>*1 PhD* | *3.2* | *4.7* | *No: 1*<br>*Yes: 4*<br>*Doesn't matter: 6* | *13* | *None: 2*<br>*Some: 4*<br>*Medium: 2*<br>*Good: 3* |

The time spent in fulfilling the tasks show a rather large spread within the groups. The spread between the groups A and B are not so large considering that some pairs in group A had to use quite a long time to get the program working. The last column shows the students' MATLAB level as indicated by the students themselves. There are only small differences between the two groups so it seems that the group distribution, at least in terms of MATLAB ability, was acceptable.

*Findings*

In this action research project we compared and evaluated the performance of two groups involved in an exercise on heat conduction during welding. The groups were compared to determine if the use of a MATLAB program, specifically designed by the instructor, helped students gain a deeper understanding of the modelling of heat conduction during welding. In the study one group had to do the programming themselves ('group A') while the other group had a pre-written program and instead studied more parameter variations ('group B'). The idea of introducing the pre-written program was to give the students more time to understand the physical problem instead of struggling with creating a functioning program. The most important results, with some subjective comments are as follows:

1. The students in group A have used more time to complete the task and from what can be seen in the tests and on the reports they have not reached the same level of understanding of the physical problem as have the group B students. This indicates an improvement in learning for those who used the pre-written code. The drawback is, of course, a decreased motivation to learn MATLAB if the student happens to be weak in that area.
2. The students in group B tested the influence of more parameter combinations, which seems to give increased understanding of the physical problem.
3. The time needed for consultation with students who had a pre-written program was decreased drastically. However, this must be counterbalanced by initial investment in time involved in writing the MATLAB program.
4. While all students except one in group B seem to be happy with their task, a few students in group A show dissatisfaction with the programming part. Not surprisingly this correlates with a limited knowledge of MATLAB programming.

## DISCUSSION

In pedagogical terms the action research that formed the basis of this study offers an exemplary model for curriculum reform. One aspect of this model is the cooperation between a subject specialist and a pedagogical expert. In this case the teacher identified a curriculum problem and sought help with defining the problem and finding the best means to solve it. The actions taken were evaluated formatively so that at different stages of the process new questions, issues and problems were identified and addressed. Given the qualitative nature of educational inquiry the 'experiment' that was conducted here cannot provide definitive answers. It did, however, confirm the teacher's professional judgement that there was a better way to explain complicated concepts with the help of tools such as MATLAB. In his judgement, and that of the pedagogical consultant he worked with, a lack of knowledge of the MATLAB program distracted students from the object of learning. In this case the object of learning was a deeper understanding of the temperature histories of each point along a weld line in order to judge the resulting properties of the joined materials. The prewritten MATLAB programme helped them achieve this learning outcome and enabled the teacher to align his aims, methods and assessment.

According to the model we propose we asked ourselves first of all why we were initiating a curriculum reform and in doing so scrutinized our motives. The fundamental reason was to improve the understanding of key concepts in an exercise on heat conduction in welding. This in turn suggested how we might carry out such a reform. In conducting the reform we were always conscious of the question 'How do we know that students will in fact gain a better understanding of the key concepts we have identified?' Knowledge of this factor was based on testing both the process and the products of student learning. The final point on our checklist was how we could go on improving the exercise that was the focus of this study. In the process of clarifying why we wanted to reform the heat conduction exercise and in carrying out our small piece of action research to carry out that reform we unearthed information that can be used to further improve this exercise and other parts of the Joining Technology course. It would be helpful, for example, to pre-test the existing knowledge that students have of MATLAB and take that into account in running the exercise. Although the focus is on heat conduction there is no reason why students with a good grasp of MATLAB should not design their own program. Highly motivated students who wish to learn more about the programming side of things might even be given the opportunity of joining such a group as long as they were pre-warned that this would involve extra work. Students with little or no knowledge of MATLAB would work with the prewritten program.

While writing this article we ran the course one more time. This time we made our learning outcomes even more specific and aligned them more closely with the assessment task. Students were able to see from the outset what exactly was required in the project report. We also gave the prewritten MATLAB code to all participants. The result was very good. We did not have to return any reports for rewriting; all reports were complete and there was a more even spread in terms of learning outcomes. During the 'experimental' exercise described in this paper there were a few 'stars', mainly people who were already good at MATLAB. In the most recent iteration of the project there were no outstanding reports but neither did any group fail. A positive endorsement of this pedagogical reform is that the examiner for the course doubled the value of the exercise so that it is now worth a full credit point. Consequently it has a weighting of 20% in terms of assessment while the exam has been reduced to an 80% weighting.

## CONCLUSION

In conclusion, we believe that although this paper focuses on a small exercise in engineering education, the principles involved in improving that component can provide a simple model for much larger curriculum reforms. These principles embrace a greater awareness of the need for a constructive alignment of clear goals and criteria-referenced learning objectives, teaching and learning methods and assessment. In our course planning we always saw MATLAB as a teaching and learning tool rather than the object of study. When the tool was seen to hinder rather than help the learning process we changed the way we used it. Instead of struggling to develop their own MATLAB programs students were provided with a custom-made program for solving problems that were designed to deepen their understanding of heat conduction during welding.

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## APPENDIX 1

*Prewritten MATLAB code for an assignment on heat conduction*

```
%Assignment on Heat Conduction in MMK 210 Joining Technology
%Johan Ahlstrom, Materials Science and Engineering, March 2003
clear;

%Input parameters
geometry=2;                    %1. Geometry 2='thin' 3='thick' plate
mtrl=1;                        %2. Material 1=Copper 2=Monel_400 3=Carbon_steel 4=Aust_steel
T0=573;                        %3. Preheat temperature K (25/300 C corresponding to 298/573K)
q=1e3;                         %4. Net power J/s
d=2e-3;                        %5. Plate thickness m (only relevant for thin plate)
z=-0.003                       %6. Depth m (z-coordinate, only relevant for thick plate)
v=2e-3;                        %7. Welding speed m/s
%End of input parameters!!!

%Material data given as [Copper Monel_400 Carbon_steel Aust_steel]
a=[9.6e-5 8.0e-6 9.1e-6 5.3e-6];     %Thermal diffusivity m^2/s
lambda=[384 35.2 41 24.9];           %Thermal conductivity J/(m*s*K)
Tm=[1336 1573 1800 1773];            %Melting temperature K

%Definition of contour plot levels
```

```
Tcurve1=[673 673];                %The command 'contour' requires vector as input
Tcurve2=[1073 1073];
Tcurve3=[1473 1473];
TcurveTm=[Tm(mtrl) Tm(mtrl)];     %Tm

%Definition of vectors for geometry definition and time
ksimin=-0.1;                      %ksimax-ksimin=ymax-ymin in combination with command
ksimax=0.05;                      % axis('square') will yield figures with equal scaling
ymin=-0.075;                      % on both axes which is important for interpretation!!!
ymax=0.075;
step=0.5e-3;

tmax=100;
tstep=0.1;
x=0.1;                            %Defines the location of the studied point in t-T diagram

ksi=[ksimin:step:ksimax]';             %ksi vector
y=[ymin:step:ymax];               %y vector
[KSI,Y]=meshgrid(ksi,y);               %coordinate matrix
t=[0:tstep:tmax];                 %Time vector

%Computation of temperature field
if geometry==2
T=T0+q/(2*pi*lambda(mtrl)*d)*exp(-v*KSI/(2*a(mtrl))).* ...
besselk(0,v*sqrt(KSI.^2+Y.^2)/(2*a(mtrl)));
else
T=T0+q/(2*pi*lambda(mtrl))*exp(-v*KSI/(2*a(mtrl))).* ...
exp(-v*sqrt(KSI.^2+Y.^2+z^2)/(2*a(mtrl)))./(sqrt(KSI.^2+Y.^2+z^2)+eps);
end

%Search the y coordinate for which the max. T is close to Tm/2 (in Kelvin)
%The index is stored in yindexTmhalf
[Tmhalf,yindexTmhalf]=min(abs((max(T')-Tm(mtrl)/2)));
%Computation of time-temperature curves
if geometry==2
Tvect1=T0+q/(2*pi*lambda(mtrl)*d)*exp(v*(v*t-x)/(2*a(mtrl))).* ...
besselk(0,v*sqrt((x-v*t).^2)/(2*a(mtrl)));
Tvect2=T0+q/(2*pi*lambda(mtrl)*d)*exp(v*(v*t-x)/(2*a(mtrl))).* ...
besselk(0,v*sqrt((x-v*t).^2+y(yindexTmhalf)^2)/(2*a(mtrl)));
else
Tvect1=T0+q/(2*pi*lambda(mtrl))*exp(v*(v*t-x)/(2*a(mtrl))).* ...
exp(-v*sqrt((x-v*t).^2+z^2)/(2*a(mtrl)))./(sqrt((x-v*t).^2+z^2)+eps);
Tvect2=T0+q/(2*pi*lambda(mtrl))*exp(v*(v*t-x)/(2*a(mtrl))).* ...
exp(-v*sqrt((x-v*t).^2+y(yindexTmhalf)^2+z^2)/(2*a(mtrl))) ...
./sqrt((x-v*t).^2+y(yindexTmhalf)^2+z^2);
end

%%%%%%%%Plotting

%Text string for material name
if mtrl==1
Materialtxt='Copper';
elseif mtrl==2
Materialtxt='Monel 400';
elseif mtrl==3
Materialtxt='Carbon steel';
else
Materialtxt='Austenitic steel';
end

%Isotherms
figure(1)
clf
hold on
[Tmax,yindexTmax]=max(max(T'));
if Tmax < Tm(mtrl)
disp('The temperatures do not reach Tm at this depth; lower T isotherms plotted');
[Ct,Ht]=contour(ksi,y,T-273);
clabel(Ct,Ht);
else
[C,H(1:2)]=contour(ksi,y,T,Tcurve1,'b-');
[C,H(2)]=contour(ksi,y,T,Tcurve2,'g–');
```

```
if (mtrl==1)
[C,H(3)]=contour(ksi,y,T,TcurveTm,'r-.');
legend(H,'400 C','800 C','1063 C (Tm)');
else
[C,H(3)]=contour(ksi,y,T,Tcurve3,'k-.');
[C,H(4)]=contour(ksi,y,T,TcurveTm,'r-.');
legend(H,'400 C','800 C','1200 C',[num2str(Tm(mtrl)-273) 'C (Tm)']);
end
end
axis('square');
axis([ksimin ksimax ymin ymax]);
title(['Isotherms for ' Materialtxt ', T0=' num2str(T0–273) 'C, electrode in (0,0)']);
xlabel('ksi (m)');
ylabel('y (m)');
%pause

% To print this graph, activate one of the following rows by deleting the '%'-sign
% For the report, either the copy figure option in the graph window, or the
% tiff-format is recommended. Write 'help print' in the MATLAB command window to
% get more information

%print isoterm
%print -dtiff isotherm

%Temperature vs Time
figure(2)
clf
hold on
plot(t,Tvect1–273,'-',t,Tvect2–273,'-.');
axis([0 tmax 0 1600]);
title(['Temperature—time curves for ' Materialtxt ', T0=' ...
num2str(T0–273) 'C at x=0.1m']);
xlabel('time (s)');
ylabel('temperature (C)');
yh=num2str(abs(y(yindexTmhalf)));
dist=['Distance from centre line ' yh 'm '];
legend('In the centre line',dist);
%pause

% To print this graph, activate one of the following rows by deleting the '%'-sign

%print tidtemp
%print -dtiff tidtemp

figure(3)
clf
mesh(ksi,y,T-273)
axis([ksimin ksimax ymin ymax 0 1600])
caxis([0 1600])
colorbar
xlabel('ksi (m)');
ylabel('y (m)');
zlabel('Temperature (C)');
```

## APPENDIX 2

*Evaluation of MATLAB exercise*

MMK 210 Joining Technology, quarter IV, 2002/2003, 2003–04–09; Johan Ahlström, Materials Science and Engineering, Chalmers University of Technology

This evaluation will not be used for grading purposes but is only intended to judge the pedagogical effect of introducing the pre-written MATLAB code. I promise that I will put definite grades on the reports before I read the answers to this evaluation form. I will document this by putting all forms in an envelope that will be sealed until the assignments are returned with grades given on the front page.

*Name:*. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
*Group:*. . . . . . . . . . . . . . . . . . *(Group A wrote the code, Group B used the pre-written code)*

**General questions**

Would you have liked to be in the other group? (Yes/No/Does not matter)
Why? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

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How much experience did you have in MATLAB programming before the exercise? . . . . . . . . . . . . . . . . . . . . . . .
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How much time did you spend on the assignment in total? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Do you consider it valuable, i.e. have you learnt much in relation to the time spent? . . . . . . . . . . . . . . . . . . . . . . .
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*For group A only:*
How much time did you spend on writing the MATLAB code? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Did you increase your knowledge on MATLAB programming? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

*For group B only:*
How much time did you spend on understanding the MATLAB code? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Did you modify it to better suit your needs? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Technical questions**
With all other parameters constant, how does the heat conductivity (k) influence the shape of the isotherms? . . . . . .
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What does that mean in terms of cooling rates—do we have higher or lower cooling rate if the heat conductivity is higher? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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With all other parameters constant, how does the preheat temperature influence the shape of the isotherms?. . . . . . .
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Why is preheating used and how does it 'work'? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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With all other parameters constant, how does the weld speed influence the shape of the isotherms?. . . . . . . . . . . . . .
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What does that mean in terms of cooling rates? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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