Integration of Polymer Processing and Advanced Quality Assurance Courses - An Injection Molding Project using Design of Experiments

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Abstract

Kettering University is a co-op college for Engineering and Managerial Studies located in Flint, Michigan. Our students alternate terms of classroom/laboratory work with terms of work experience with their corporate sponsors. Because of this unique education system, it is important that our students are able to apply their classroom/laboratory experience to solve the problems they encounter during their work terms. Since the Industrial and Manufacturing Engineering Department has a polymer processing laboratory, which provides the students with hands-on manufacturing experience in injection molding, extrusion, and material characterization, it is a reasonable place to create near "real world" projects for class integration in problem solving.

The Advance Quality Assurance (AQA) course offered by the IE program is a process quality improvement course which covers Design of Experiments (DOE), Response Surface Methodology (RSM), and Quality Control Charts. The Polymer Processing course taught by the ME faculty studies how polymeric materials are affected by processing parameters. One of the major topics in the course is the study of injection molding, its optimization, and trouble shooting. This pilot project to integrate the two courses is a consequence of the demand from industry. As a result of the integration, IE students will acquire knowledge of the injection molding process and ME students will learn DOE techniques. The step-by-step DOE technique was applied to an injection molded tensile bar, which demonstrated what to be studied in the experiment, how to conduct the experiment, how to collect and analyze data, and how to draw practical conclusions on the basis of the data.

This paper will show the roadmap and discuss the process and the outcome of the integration of AQA, an industrial engineering course and Polymer Processing, a manufacturing course.

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Introduction

In today's global economic environment, it is necessary for corporate America to be competitive by manufacturing products with lower cost, higher quality and quick response time-to-market. To meet such challenge, the industry requires that engineers are not only proficient in their own field but also well versed in other disciplines.

Kettering University is integrating cross-disciplinary engineering courses through integrated common projects to ensure that our graduates are equipped with problem solving skills to handle real world projects.

The AQA course offered by the IE program covers Design of Experiments (DOE), Response Surface Methodology (RSM), and Quality Control Charts. While the Polymer Processing course taught by the ME faculty studies how polymeric materials are affected by processing parameters. One of the major topics in the course is the study of injection molding, its optimization, and trouble shooting. The integration of AQA and Polymer Processing using DOE as the common laboratory project is the perfect vehicle for both courses.

The objectives of this pilot study are to:

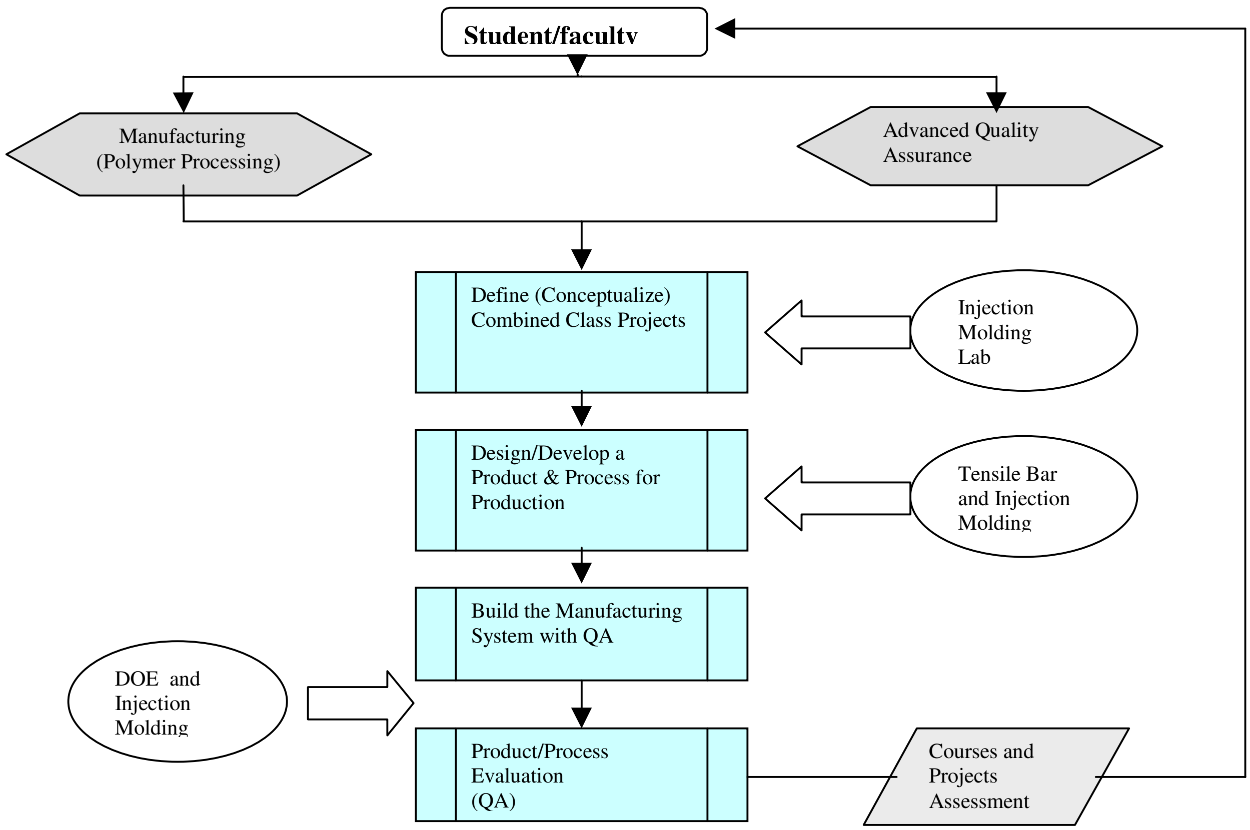
1. Reinforce learning through peer interactions and discussions
2. Provide relational learning experience across disciplinary topics
3. Create a real world experience of cross-disciplinary working teams for students

Integration Process and the Roadmap

The integration process is diagrammed in Figure 1 and outlined below.

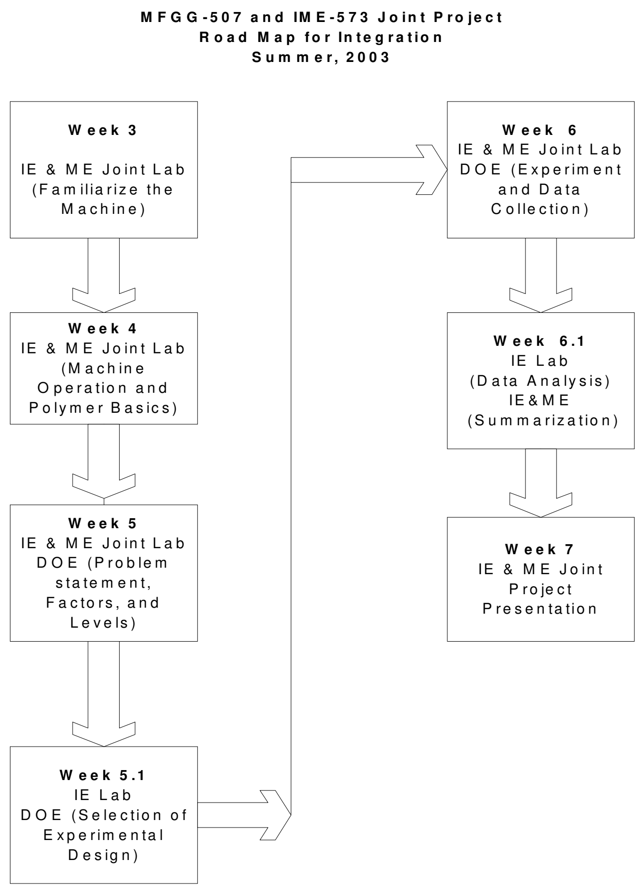
1. Begin with faculty and students who understand the need for cross-disciplinary education to interaction and collaboration, which is industry driven.
2. Integrate cross-disciplinary courses such as AQA and Polymer Processing.
3. Define common class project as injection-molding using DOE.
4. Design/develop a product and process for production, i.e., design/develop injection-molding to manufacture tensile specimens.
5. Build the manufacturing system with quality assurance in order to investigate and improve the process.
6. Implement product and process evaluation using DOE for process improvement.
7. Conduct courses and project assessment with feedback to the faculty and students for continuous improvement.

Figure 1. Integration Through Common Project Process



In the summer of 2003, we started the integration of AQA and Polymer Processing by following the integration process shown in Figure 1 as the roadmap for future collaboration among faculty across disciplinary engineering programs. The initial roadmap and timeline is shown in Figure 2. Before the term began, both the IE and ME faculty agreed on the scope of the integration, feasible class projects, common lab hours, and time line for the labs and the project. Teams formed in the first week were limited to 4-5 students with a rough balance of IE and ME students.

Figure 2. Common Project Integration Roadmap



Injection Molding and Design of Experiments

Today's injection molding industry companies require short product development time and design cycles to be competitive in terms of growth and profitability. Typical injection molding machines have many parameters (factors) that affect the characteristics of finished products. To determine the appropriate process parameters' setting, a traditional approach using trial and error is no longer adequate. Design of Experiments (DOE) is a statistical tool that has emerged as one of the most effective methods for investigating injection-molding in the R&D, product design and process phases. It can also be used when setting up new molds and trouble shooting problem jobs.

A designed experiment involves systematic, controlled changes of input variables (factors) of a process in order to observe the corresponding changes in the outputs (responses). Experimental data are collected and analyzed so that valid and objective conclusions are obtained.

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To use DOE, it is necessary that both the IE and ME students have a clear idea of exactly what is to be studied, how the data are to be collected, and how the data are to be analyzed. An outline of this procedure (Montgomery, 2001) is shown in Table 1.

Table 1. Guidelines for Designing an Experiment

1. Statement of the Problem
2. Choice of Factors, Levels, and Ranges
3. Selection of Response Variable
4. Choice of Experimental Design
5. Performing the Experiment
6. Analysis of Experimental Data
7. Conclusions and Recommendations

An Integrated Injection Molding Experiment Team Project

There are two goals for the injection-molding process investigation using DOE. The first is to identify the significant input variables (factors) that affect the process output, and second is to establish a meaningful relationship (regression model) between the significant input variables and the process output (response). The response variable in the study is a quality characteristic of plastic part - the weight of a tensile bar. In this paper, only one team's DOE project will be presented.

Based on the discussion and the guidance of the ME faculty, four factors: pack pressure (A), pack time (B), injection speed (C), and mold cooling time (D), were identified as possible candidates for the input variables (factors). IE faculty and students discussed the possible designs that are feasible and efficient for the process. It was decided that a simple 2^4 (four factors with two levels for each factor) full factorial design with duplicate measurements would be appropriate. The settings (two levels, low and high) for each factor were determined with the help of ME faculty and students. These are shown in Table 2.

Table 2. Factor and Level Settings

Factor	**Low(-)**	**High(+)**
A - Pack Pressure	200 psi	400 psi
B - Pack Time	3.5 seconds	9.0 seconds
C - Injection Speed	2.5 in/sec	4.0 in/sec
D - Mold Cooling Time	20 seconds	30 seconds

In this experiment, there are 16 (2^4) randomized runs. Four consecutive tensile bars were manufactured for each run. The experimental design is called the experiment with duplicate measurements (Montgomery, 2001). Statistical software MINITAB is used to generate the randomized run order shown in Table 3. For example, the first experimental run is to set factor A (pack pressure) at high level, factor B (pack time) at high level, factor C (injection speed) at low level, and factor D (mold cooling time) at low level. The IE students in each team will generate the 16 runs and conduct the experiment with the ME students in the team. The weight was measured to the nearest 0.1 gram and the data are shown in Table 4.

Table 3. Experimental Run Order

StdOrder	RunOrder	Pack Pr.	Pack Time	Inj.Speed	Cool.Time
4	**1**	**400**	**9.00**	**2.50**	**20**
1	2	200	3.50	2.50	20
12	3	400	9.00	2.50	30
2	4	400	3.50	2.50	20
15	5	200	9.00	4.00	30
14	6	400	3.50	4.00	30
11	7	200	9.00	2.50	30
9	8	200	3.50	2.50	30
6	9	400	3.50	4.00	20
3	10	200	9.00	2.50	20
10	11	400	3.50	2.50	30
8	12	400	9.00	4.00	20
7	13	200	9.00	4.00	20
13	14	200	3.50	4.00	30
16	15	400	9.00	4.00	30
5	16	200	3.50	4.00	20

Table 4. Part Weight Data

StdOrder	RunOrder	Pack Pr.	Pack Time	Inj.Speed	Cool.Time	Weight - a	Weight - b	Weight - c	Weight - d
4	1	400	9.00	2.50	20	9.4	9.4	9.4	9.4
1	2	200	3.50	2.50	20	8.9	8.9	8.9	8.9
12	3	400	9.00	2.50	30	9.4	9.4	9.4	9.4
2	4	400	3.50	2.50	20	9.2	9.2	9.2	9.2
15	5	200	9.00	4.00	30	9.0	9.0	9.0	9.0
14	6	400	3.50	4.00	30	9.2	9.2	9.2	9.2
11	7	200	9.00	2.50	30	9.0	9.0	9.0	9.0
9	8	200	3.50	2.50	30	8.9	8.9	8.9	8.9
6	9	400	3.50	4.00	20	9.2	9.2	9.2	9.2
3	10	200	9.00	2.50	20	9.0	8.9	9.0	9.0
10	11	400	3.50	2.50	30	9.2	9.2	9.2	9.2
8	12	400	9.00	4.00	20	9.4	9.4	9.4	9.4
7	13	200	9.00	4.00	20	8.9	8.9	8.9	8.9
13	14	200	3.50	4.00	30	9.0	9.0	9.0	9.0
16	15	400	9.00	4.00	30	9.4	9.4	9.4	9.4
5	16	200	3.50	4.00	20	8.9	8.9	8.9	8.9

After the experiment was completed and data collected, the IE group in each team used MINITAB to analyze the data. In the duplicate measurements experiment, the analysis will be based on the average weight of the four measured parts for each run. The normality plot of the effects was obtained from MINITAB to identify the significant effects. The result is shown in

Figure 3. By examining the plot, it is concluded that factor A (pack pressure), factor B (pack time) and AB interaction are statistically significant. This means that pack pressure, pack time and the interaction have significant effects on part weight. MINITAB also produced main effects plot and AB interaction plot shown in Figure 4 and Figure 5 respectively. The main effect is a quantitative measure of the impact of the factor on the part weight. The lack of significant main effects by injection speed (C) and cooling time (D) can be seen from the main effects plot.

Figure 3. Normality Plot of Effects

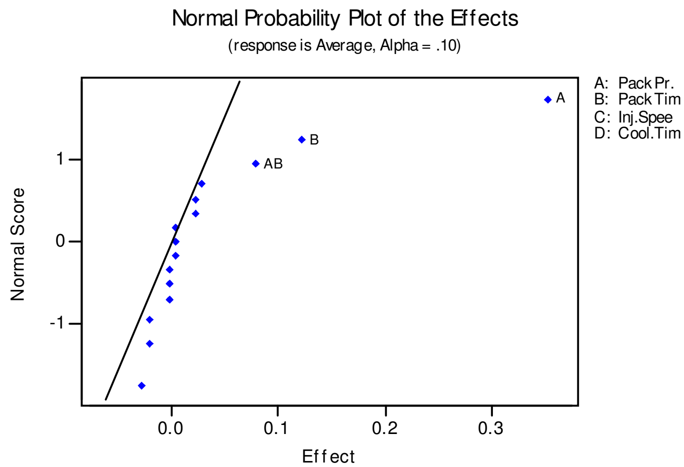


Figure 4. Main Effects Plot

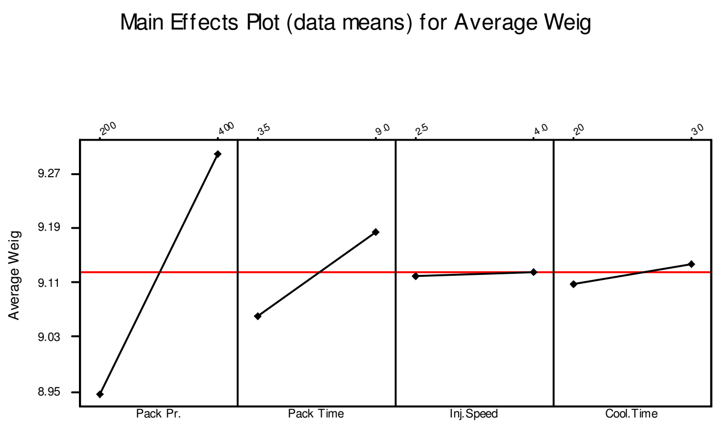
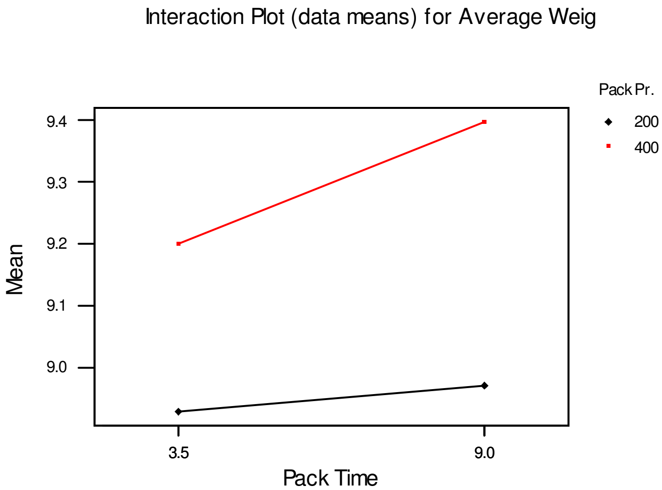
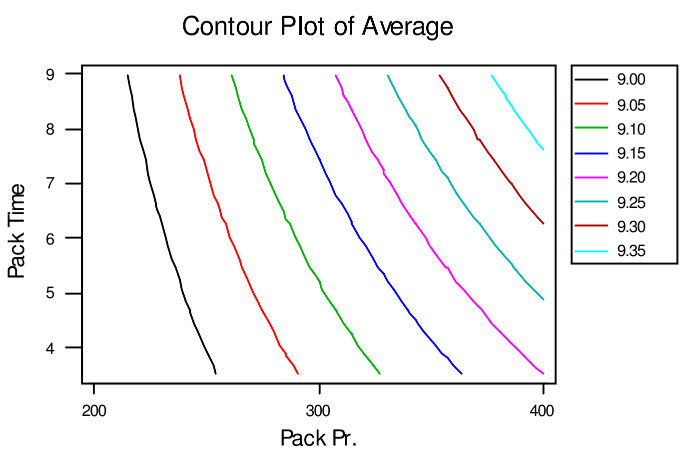


Figure 5. AB Interaction Plot



The contour plot for factor A and factor B shown in Figure 6 indicates that higher pack pressure and higher pack time will produce a heavier tensile bar within the setting ranges.

Figure 6. Contour Plot



Team member interaction is crucial after the data analysis. ME students will provide insight on properties of the plastic and injection molding machine to assess the validity of the conclusions.

To further investigate the relationship between tensile bar weight and the significant factors A (pack pressure), B (pack time) and AB interaction, an estimated regression model for the part weight and the significant effects can be obtained using MINITAB. The estimated equation is given below:

y (weight) = 8.72 + 0.000878 pack-p – 0.0205 pack-t + 0.000142 (pack-p)*(pack-t)

The following conclusions can be made based on the experimental data analysis.

1. Pack pressure and pack time have significant impact on the tensile bar weight.
2. The interaction between pack pressure and pack time indicates that higher pack pressure and pack time will produce heavier tensile bar within the ranges.
3. An estimated regression model can be developed to estimate the tensile bar weight.

Integration Assessment

This pilot integrated project turned out to be successful. The joint labs and project provided faculty and students to work as teams. The following are students' comments and inputs:

1. Project Learning Experience

- Project provides an invaluable opportunity to work with the ME students.
- Project provides excellent opportunity to work with the IE students.
- Working on the integrated team gave students real world working experience to reinforce the concept of concurrent engineering.
- It was beneficial to learn the basics of the injection molding process, the operation of the machine, and polypropylene.
- Both the IE and ME students learned the important application of DOE to deal with the real world problems.

2. Team Work

- Hands on learning with another class we would otherwise have no contact with.
- Both the IE and ME students learned from each other.
- The IE learned the injection molding process, operation of the machine from ME students, and the ME learned how to apply DOE to a real world project.
- Students' interaction is a good experience.

3. Continuous Improvement

There are some areas where the improvements are needed.

- From the IE side, factorial experiment should be covered as early as possible so the flow of the labs will be more time efficient.
- The scope of the project outcomes should be clearly stated. It is not clear how much data analysis is needed.
- Report writing and project presentation guidance will be helpful.
- Closer collaboration between professors should be made.

Summary

This paper presented a process and roadmap to integrate two cross-disciplinary engineering courses. From team reports, presentations, students' comments and inputs, the integration provided a real world learning environment for the students. This pilot study was just a beginning for the integration of AQA and Polymer Processing. We are in the process of planning the next summer project based on the experience we had learned in the summer of 2003. A continuing education (CE) program combining injection molding and DOE is also in the planning stage. These are the results of Kettering University's willing to nurture the integration through inter-department collaboration.

Acknowledgement

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Biography

TONY LIN, Ph.D. is a professor of Industrial engineering at Kettering University. His special areas are in Reliability and Quality Engineering, Design of Experiments, and Operations Research. He has actively involved in research and consulting in these areas. Dr. Lin is a Certified Reliability Engineer and a member of ASEE, ASQ, and IIE.

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