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A Study of Process Variability of the Injection Molding of Plastics Parts Using Statistical Process Control (SPC)

Dr. Rex C Kanu, Ball State University

Dr. Rex Kanu is the coordinator of the manufacturing engineering technology program at Ball State University, where he teaches plastics materials and processing.

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Abstract

Process variability in the manufacturing of products is a serious concern, which, if left unchecked, could lead to product wastes, low productivity, and poor quality products[1]. To prevent these unwanted effects from happening, statistical process control (SPC), a statistical tool, is used to monitor and control process variability. SPC assumes that manufactured products have measureable attributes such as mass, dimensions of the products, mechanical properties, and visual appearance to name a few. These attributes are affected by natural and assignable causes. Natural causes are inherent to the process and may include variables such as ambient temperature, machine vibration, and relative humidity - variables that are often very difficult to control. Unlike natural causes, assignable causes are controllable and may include items such as bad or worn-out machine components that should be replaced. By monitoring a process, an assignable cause is detected when process variability exceeds the expected range caused by natural causes. The primary advantage of SPC is that it detects a faulty process, which if corrected, prevents the manufacturing of defective products. This is unlike traditional quality control practice that identifies defective products after they have been produced. The traditional method of quality control leads to a costly manufacturing process.

In a manufacturing engineering technology program, SPC was used to monitor and control the injection molding of plastics parts (since the word "plastic" means deformable, it has been the tradition in the plastics industry to use the word "plastics" to avoid any confusion. Hence, the phrase, plastics resins or plastics raw materials). Students monitored several injection molding process variables using SPC *x-bar* and *range* control charts while producing 300 plastics parts. The mass of the products was used as an attribute representing parts quality. After analyzing the process data, students were able to determine whether the process was stable, that is, in control. An assessment of students' learning outcomes showed a 25% improvement in their understanding of SPC when applied to a manufacturing process such as the injection molding plastics parts.

Introduction

In a manufacturing engineering technology program of a Mid-Western University, statistical process control (SPC) and plastics injection molding are taught as separate courses. This study is an attempt to apply materials covered in both courses to enhance students' understanding of plastics injection molding and SPC, but this project was done in a plastics processing course. To this end, students produced 300 American Standards for Testing and Materials (ASTM) tensile and impact specimens, while examining the variability of process parameters that impact parts quality. In this work, part mass was used as a marker for the entire process being unstable while variability of the process parameters was considered as the cause for the process being unstable.

Experimental

Process Flow Diagram

To identify the process parameters to examine, students created a process flow diagram and selected process parameters they thought could affect parts mass if process variability occurred in these parameters. Figure 1 shows the process flow diagram for the injection molding component of the study. The parameters chosen for the study were cooling time, cushion final position, plasticizing time, and screw position at change-over.

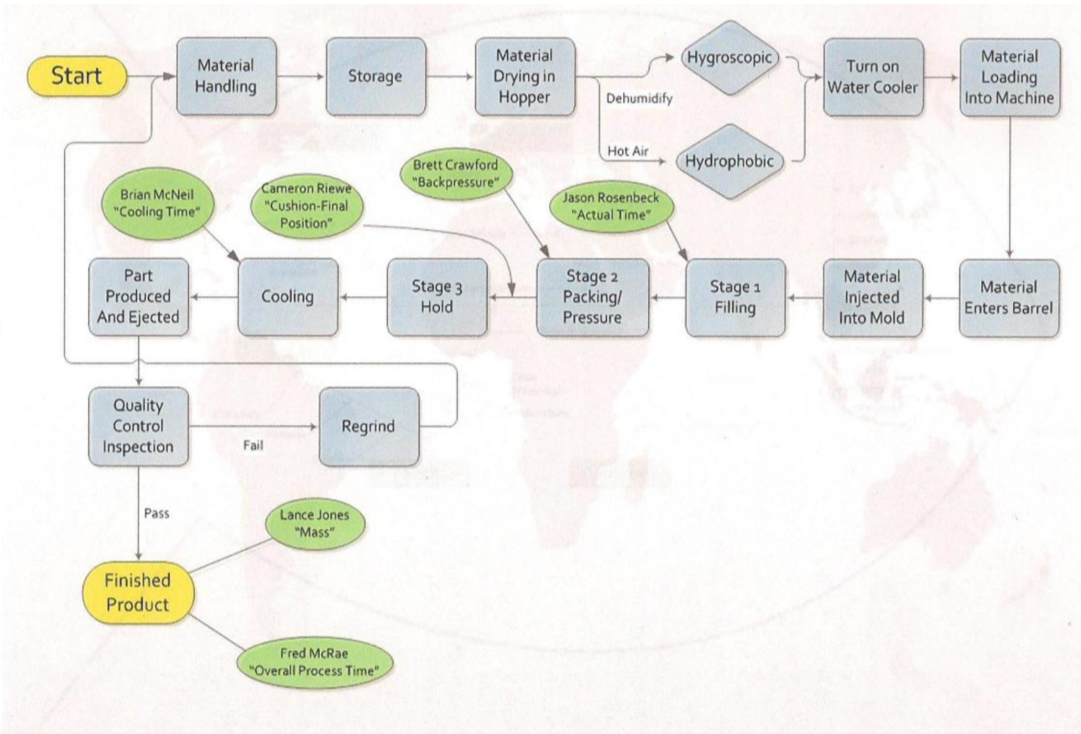

Figure 1. Process Flow Diagram of Plastics Injection Molding

Material

The plastics resin used in this work was polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS) blend manufactured by Bayer. The trade name of the resin is BayBlend® FR 2010. The resin was dried at 200 °F with a dehumidifying dryer for four hours before processing parts.

Equipment

Conair Mobile Drying and Conveying Unit (Model MDC-30) was used for drying the plastics resins prior to injection molding parts. A 60-ton Sandretto Injection Molding Machine was used for processing the ASTM tensile and impact specimens. This machine was not equipped with real-time SPC capabilities, so the actual SPC assessment of the process was done post-injection molding of the specimens. The mold temperature was controlled with a Conair Thermolator (mold temperature controller). For this mold temperature was set at 150 °F based on the recommendation of the resin manufacturer, Bayer.

The processing parameters of the injection machine were

- Rear barrel temperature: 400 °F
- Middle barrel temperature: 410 °F
- Front barrel temperature: 420 °F
- Nozzle temperature: 440 °F
- Back pressure: 50 psi.

Data Collection

The Sandretto injection molding machine had the capability for data collection. Hence, after each injection molding cycle, the machine printed, through a printer, the parameters identified by the students in Figure 1. After each cycle, each part produced was labeled and weighed after about 48 hours with an electronic scale.

Statistical Process Control (SPC)

After setting up the injection molding machine, students processed good parts/specimens to ensure that an ideal processing condition existed before collecting data. Good parts/specimens are defined as those that did not have sink marks, short shot, splays, flash, or contaminants. Data were collected for 300 consecutive parts. These parts divided into 30 subgroups consisting of ten parts. However, data of five consecutive parts with a subgroup were used to represent the characteristics of the subgroup as shown in Table 1 for injection cushion final position. AT&T statistical quality control standards for *x*-bar and *R* charts where the subgroup size is at least four were used to determine if the process parameters were statistically in-control (stable) or out-of-control (unstable). The rules[2] are

A) 1 point above Zone A (1-sigma from the centerline)
B) 1 point below Zone A
C) 2 of 3 successive points in upper Zone A or beyond
D) 2 of 3 successive points in lower Zone A or beyond
E) 4 of 5 successive points in upper Zone B (2-sigma from the centerline) or beyond
F) 4 of 5 successive points in lower Zone B or beyond
G) 8 points in a row above centerline
H) 8 points in a row below centerline
I) 15 points in a row in Zone C (3-sigma from the centerline) (above and below center)
J) 8 points on both sides of center with 0 in Zone C
K) 14 points in a row alternating up and down
L) 6 points in a row steadily increasing or decreasing

Table 1. Injection Machine Cushion Final Position, Unit in (%) of Maximum Injection Stroke

Table 1

Subgroup		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample Measurements	1	0.3	0.0	0.1	0.0	0.4	0.3	0.3	0.3	0.6	0.3	0.2	0.3	0.3	0.2	0.2
	2	0.0	0.1	0.1	0.0	0.3	0.3	0.3	0.3	0.2	0.1	0.2	0.3	0.3	0.3	0.2
	3	0.1	0.0	0.0	0.4	0.2	0.3	0.3	0.4	0.3	0.3	0.2	0.3	0.2	0.2	0.2
	4	0.1	0.1	0.1	0.5	0.2	0.3	0.5	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.2
	5	0.0	0.0	0.0	0.5	0.3	0.3	0.3	0.3	0.1	0.2	0.2	0.2	0.3	0.2	0.4
AVERAGE		**0.1**	**0.04**	**0.06**	**0.28**	**0.28**	**0.3**	**0.34**	**0.3**	**0.3**	**0.22**	**0.2**	**0.28**	**0.28**	**0.24**	**0.24**
RANGE		**0.3**	**0.1**	**0.1**	**0.5**	**0.2**	**0.0**	**0.2**	**0.2**	**0.5**	**0.2**	**0.0**	**0.1**	**0.1**	**0.1**	**0.2**

Table 1 (cont.)

Subgroup		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Sample Measurements*	1	0.3	0.2	0.3	0.4	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.2
	2	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.3	0.0	0.2	0.2
	3	0.3	0.3	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.2	0.1	0.1	0.2
	4	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.2	0.2	0.1	0.1	0.1
	5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.0	0.2	0.2
AVERAGE		**0.26**	**0.24**	**0.24**	**0.24**	**0.2**	**0.2**	**0.22**	**0.22**	**0.22**	**0.26**	**0.2**	**0.22**	**0.06**	**0.16**	**0.18**
RANGE		**0.1**	**0.1**	**0.1**	**0.2**	**0.0**	**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**

*Units for cushion final position are in percent

Discussion of Results

A statistical software, Minitab-16, was used to analyze the data. Figure 1 shows the *x*-bar and *R* control charts for product mass, which was designated as a marker for the process being unstable. Figure 1 showed that the control charts were out-of-control because of the points labeled (1) that are located above the upper control limits (UCL) and below the lower control limits (LCL).

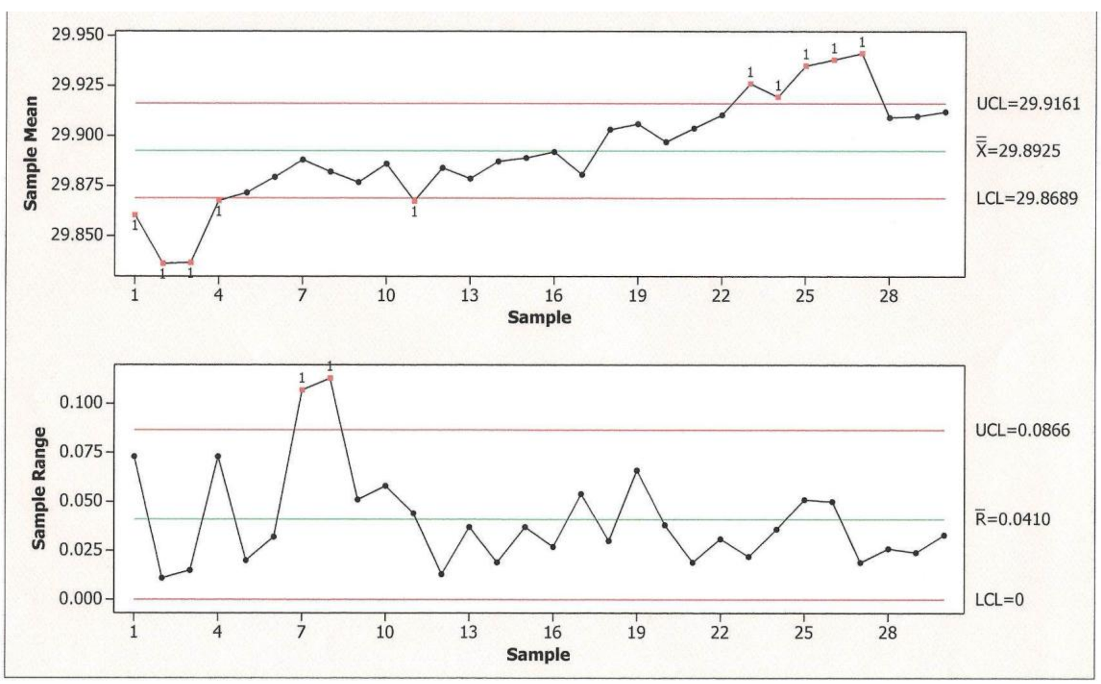

Figure 1. *X*-bar and *R* Control Charts for Product Mass

A review of Figures 2, 3, 4, and 5 shows that the process parameters control charts were statistically out-of-control. Figures 2, 3, and 4 show that the control charts for cushion final position, screw change-over position, and actual cooling time were out-of-control because several points were located outside the control limits. Figure 5 shows that the control chart for plasticizing time was out-of-control because there were 8 points in a row below the centerline.

Since the process was unstable it had the potential of producing poor quality products. To stop this from happening, the sources of the variability have to be eliminated. For this study, it appeared the cushion final position, screw change-over position, actual cooling time, and plasticizing time were the sources of the variability. The next step in eliminating the source of the process variability would be to use the design of experiments[3] to identify which of the process parameters has the largest impact on the process variability. Once identified the process parameter would be further studied to make the process stable.

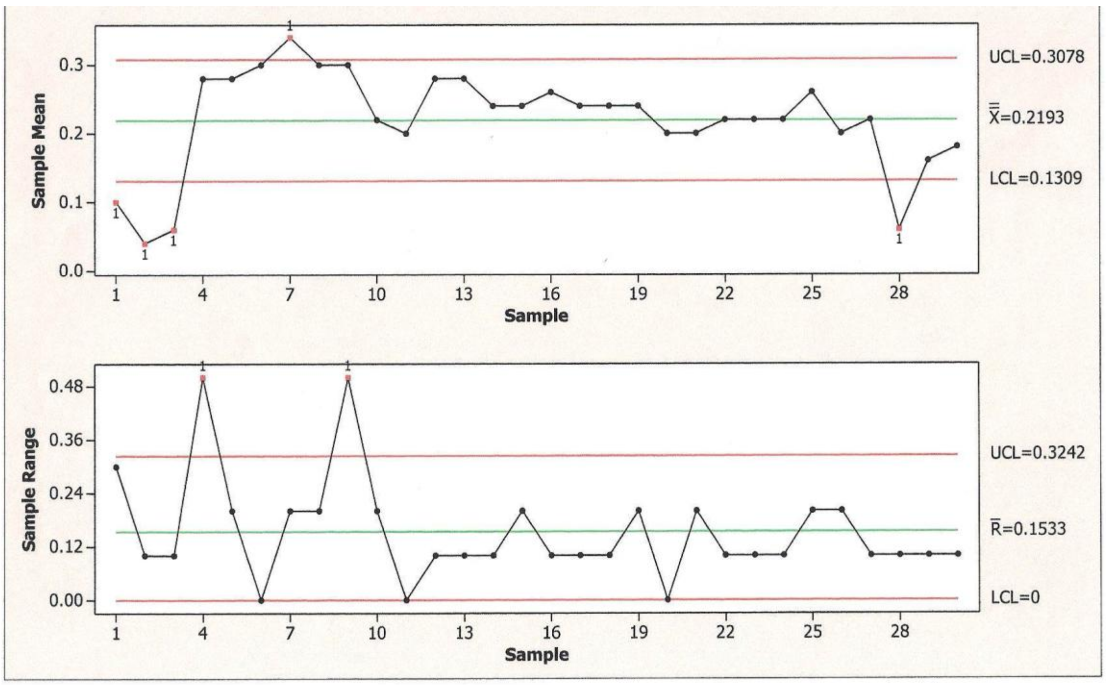

Figure 2. *X*-bar and *R* Control Charts for Injection Cushion Final Position

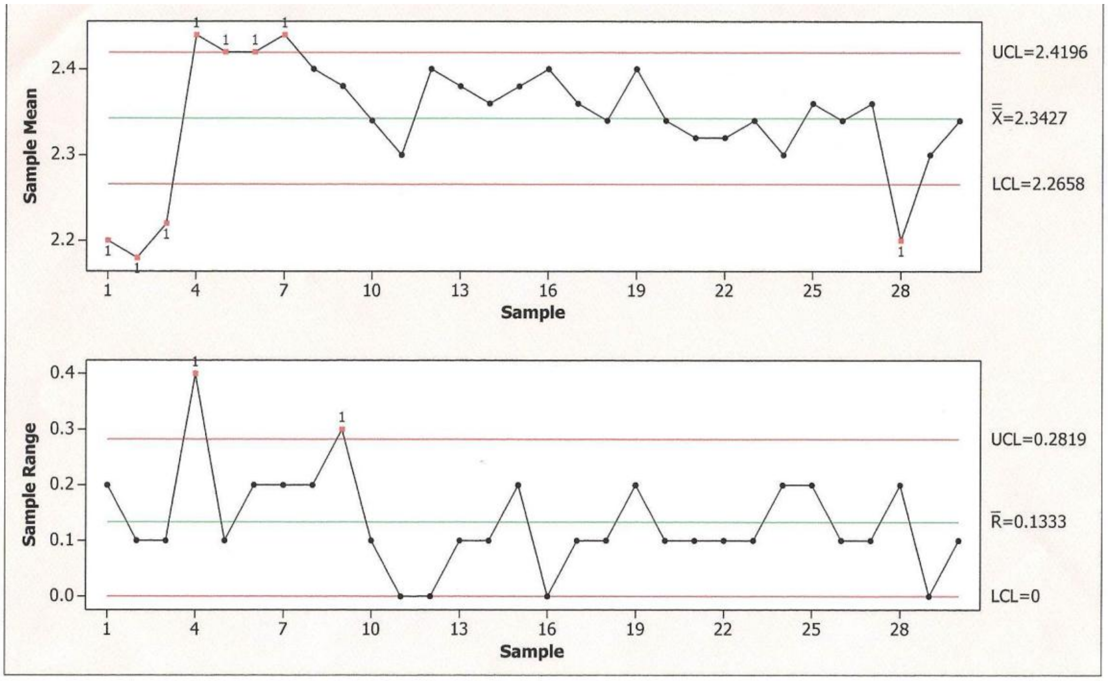

Figure 3. *X*-bar and *R* Charts for Screw Actual Position at Change Over Point

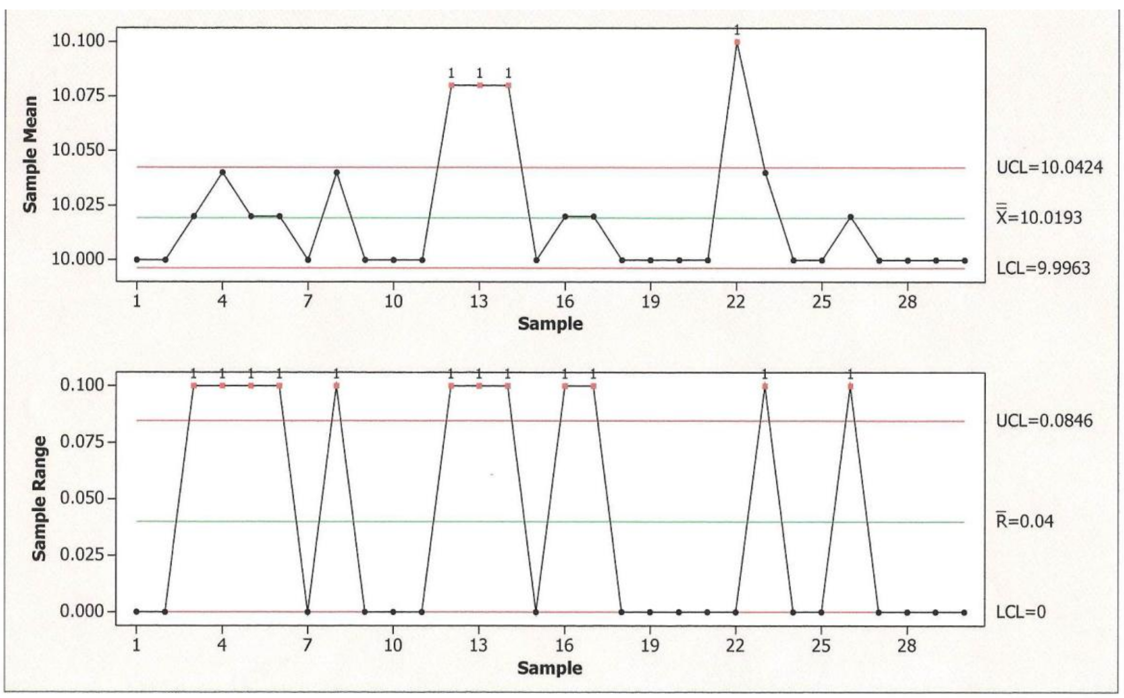

Figure 4. *X*-bar and *R* Charts for Actual Cooling Time

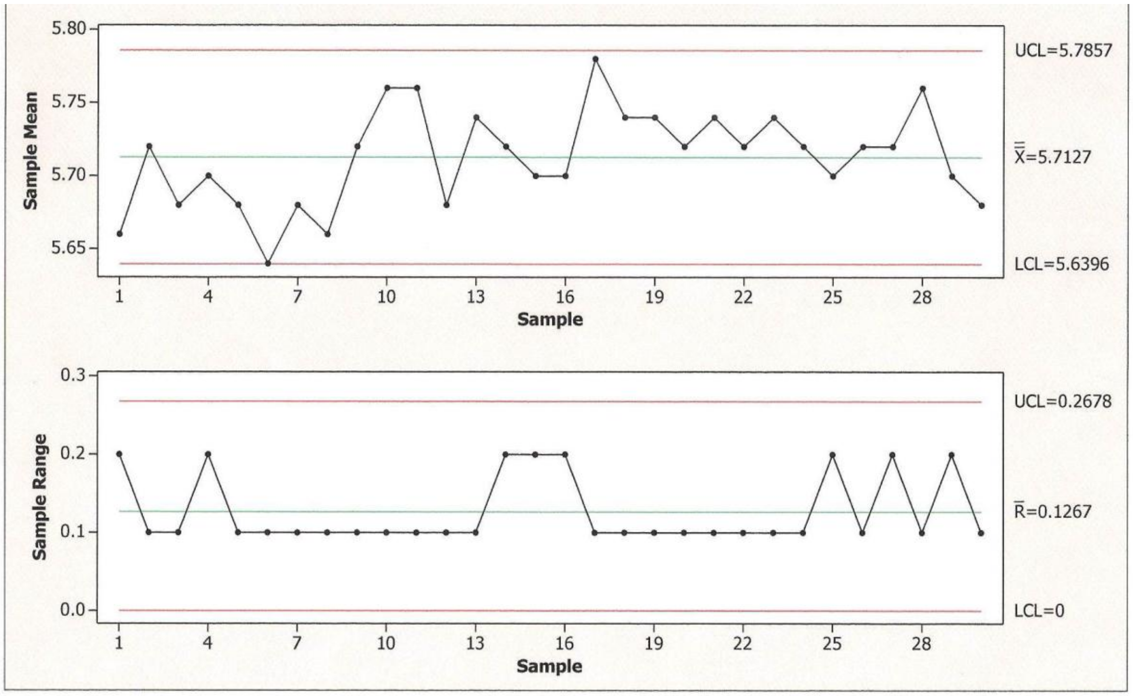

Figure 5. *X*-bar and *R* Charts for Plasticizing Time

Students Learning Outcome

The results of a survey given to students suggest that their participation in the project helped reinforce the understanding of statistical process control (SPC). Prior to undertaking the project, students rated their understanding of SPC at 58% (2.3/4.0) on the average. After completing the project, they rated their undertaking of SPC at 83% (3.3/4.0) on the average.

Conclusion

The findings of this study show that students' understanding of SPC is reinforced if they undertake projects that integrate materials learned in two or more courses. This approach exposes students to the benefits of their education and may improve their motivation to learn.

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