AC 2012-3811: TEACHING CONTROL CHARTS FOR ATTRIBUTES USING THE MOUSE FACTORY

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Teaching Control Charts for Attributes using the Mouse Factory

Abstract

The Mouse Factory contains a set of web-based, active learning modules for teaching statistical quality control. This paper will present teaching control charts for attributes using the Mouse Factory. The current pedagogy in today's classrooms is based upon lectures and homework problems from textbooks. This approach typically focuses on the knowledge and application domains of Bloom's Taxonomy. The current pedagogy removes students from applying higher order cognitive skills. By using the Mouse Factory, students must select the most appropriate improvement project to undertake, design a sampling plan, implement a control chart and evaluate the effectiveness of the implement control chart. Assessment of student behavior and attitudes will be discussed and evaluated.

Introduction

The American Society for Engineering Management (ASEM)[1] defines engineering management as "the art and science of planning, organizing, allocating resources, and directing and controlling activities which have a technical component." Quality-related activities are widely accepted as an important field of engineering management and industrial engineering. In today's global and highly competitive business environment, high quality products and services are a necessity. Quality is one method in which organizations compete[2]. The Society of Manufacturing Engineers (SME)[3,4] has conducted competency surveys and has repeatedly identified quality as an important competency gap.

This paper will present a method to address the quality competency gap in the use of control charts for attributes. In particular, control charts for nonconformity data or c charts will be examined. Control charts, in general, are one of the most important tools for quality control and improvement[5]. Montgomery[5] states that control charts have common usage in many industries due to the following reasons: 1) control charts are a proven technique for improving productivity, 2) control charts are effective in defect prevention, 3) control charts prevent unnecessary process adjustments, 4) control charts provide diagnostic information, and 5) control charts provide information about process capability. This research will present a method for teaching engineering students the use of c control charts for nonconformity data.

Another important gap is in the pedagogy used to teach quality control and control charts in many engineering curriculums. It is the authors' experiences that most engineering instruction is still conducted in a lecture format. While lecturing is an excellent method of communicating large amounts of information, students are experiencing passive learning and the amount of learning that occurs is often small[6]. There are many excellent textbooks, such as Montgomery, that provide explanations and practice problems. However the use of textbook and homework problems stress the categories of knowledge, comprehension and application in Bloom's Taxonomy[7] of cognitive skills. But this mode of instruction is less likely to emphasize the higher-order cognitive skills of analysis, synthesis and evaluation.

This paper will present research on developing and implementing a web-based, active learning module that teaches students the use of control charts for nonconformity data. Learning activities are designed to emphasize higher-order cognitive skills. Results of implementing the learning module in a senior-level Manufacturing Engineering course are presented. Conclusions and future research are presented in the final sections.

Mouse Factory

The Mouse Factory is a web-based simulation of a manufacturing plant for computer mice. There are two major components to the Mouse Factory. The first major component is a (html) website that contains a complete description of the Mouse Factory. Figure 1 shows the plant layout for the Mouse Factory. The plant layout contains "hot zones" that allow the user to click to view the details of any portion of the Mouse Factory. At the bottom of the plant layout page is a link to the bill of materials. The bill of materials shown in Figure 2 contains a list of all materials required to make a computer mouse and production information. Quality related information is found from the bill of materials by clicking on the critical points hyperlink. Figure 3 displays the critical point information for the mouse cover. The cover contains one inspection point, the post diameter, where a control chart may be applied. In addition to the variables information, attributes data describing possible non-conforming items and non-conformities is also contained in the critical point webpage.
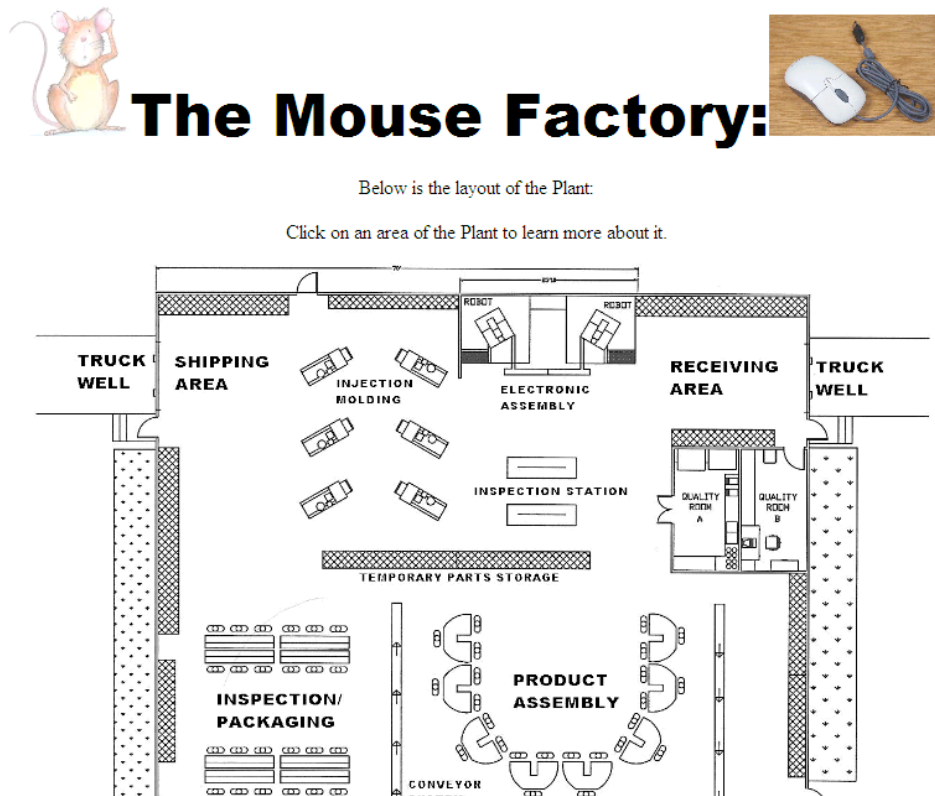

Figure 1. Plant Layout

The Mouse Factory contains nine inspections points in which control charts for variables may be implemented. An inspection point may be in one of three states: in-control with a Cp of 1.0, out of control with a minor special cause (small shift in mean) or out of control with a major special cause (large shift in mean). Additionally there are thirty different non-conforming items on six parts and thirty different nonconformities on six different parts. Non-conforming items and nonconformities may also be present in three states similar to the inspection points for control charts for variables. This system allows 400,500,000 different configurations to be created. Thus each student is practically guaranteed to receive a different configuration.

A second web-based application developed in Java Server Faces (JSF) is available for the control charts for the control chart for variables learning module. JSF is a server-side user interface component for Java technology-based web applications[8]. JSF enables the use of backing beans, JavaBeans components, to store information and execute methods (subroutines). The advantage of this architecture is the separation between behavior and presentation. The second web application provides the following functionality: 1) provides historical data for constructing control charts, 2) implement control chart in manufacturing plant and 3) gather production and quality records to evaluation impact of control charts. This module assumes that the control charts for nonconformity data performs a corrective action. That is the special cause is removed when the control chart signals but returns to the process at a later random time. The web-based module was written in Netbeans and utilizes the Glassfish application server. A MySQL database maintains the Mouse Factory information and student records. A major advantage of this approach is that Netbeans, Glassfish and MySQL are all open-source software packages.

Bill Of Materials:

Click Here To Go Back To The Index.
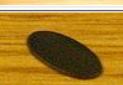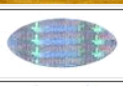
Part #	Image (Click on a part for a detailed description)	Critical Points	Component Name	Material Used	Mfg. Process	Qty.	Production Rate	Manufacturing Cost $ / Piece
1		Click Here for Critical Points	Cover	ABS White Plastic	Injection Molding	1	8 at a time	$ 0.300
2		Click Here for Critical Points	Buttons	ABS White Plastic	Injection Molding	1	8 at a time	$ 0.200
3		Click Here for Critical Points	Base	ABS Grey Plastic	Injection Molding	1	8 at a time	$ 0.300
4		None	Glide	Plastic / Adhesive	Outsourced	4	-	$ 0.005
5		None	Hologram	Roll of Sticker Labels	Outsourced	1	-	$ 0.010

Figure 2. Bill of Materials

Cover (Critical Points):

Top View
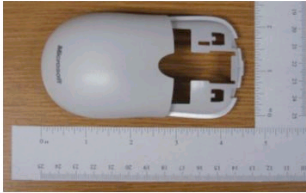
Isometric View

Bottom View

Part #	Component	Material Used	Mfg. Process	Qty.	Production Rate	Manufacturing Cost $ / Piece
1	Cover	ABS White Plastic	Injection Molding	1	8 at a time	$ 0.300

Cover: This part is made from WHITE ABS plastic by an injection molding process. The plastic injection machine used can make 8 parts at a time. It makes up most of the visible top portion of the mouse.

Critical Assembly Points:

2 Screw Mounts for Weight Located on COVER: The 2 screw mounts are inserted into a pair of matching holes located on the part BUTTONS (They have a very tight fit).

Top View of Critical Points

Location of these two posts is critical for assembly.

Outer Diameter Specifications for the 2 Posts:

Upper Specification Limit (USL): 0.2002"

Lower Specification Limit (LSL): 0.1918"

Additional Quality Issues

The following production issues are associated with non-conforming covers:

- Short shot,
- Poor weld line,
- Sink spots,
- Mold flashing,
- Warpage.

The following production issues are non-conformities on the cover:

- Bubbles,
- Burn spot,
- Surface imperfections,
- Black streaking,
- Part sticking in the mold.

Click Here To Go Back To The Inspection Station.

Click Here To Go Back To The Bill Of Materials.

Figure 3. Critical Point - Cover

SPC Lab Four

The fourth SPC laboratory allows students to design, implement and evaluate the impact of implementing a c control chart within the Mouse Factory. In the first SPC laboratory, students used common SPC tools such as checksheets and Pareto diagrams to identify the sources of nonconforming data and nonconformities to which a control chart will be applied. The fourth SPC laboratory contains four components: assignment, rubric, Mouse Factory website and Control Chart for Nonconformity Data web-based application.

The fourth SPC laboratory contains the following four learning goals:
1. Design a sampling plan for a c control chart,
2. Perform a retrospective analysis for the c control chart,
3. Implement the control chart in the Mouse Factory
4. Evaluate the effect of implementing the control chart for parts with nonconformities upon the quality of the Mouse Factory.

An important consideration in developing the learning goals was a focus on higher-order cognitive skills. Based upon the learning goals, a list of deliverables is provided to the students. Students are required to provide:
- A professional, type written report,
- A detailed discussion of their sampling plan (students may be required to sample every unit),
- A set of control limits for use in online monitoring,
- Implementation of the control chart in online use for x days,
- A new benchmark of production and quality metrics (total parts, good parts, bad parts and off-spec parts) from the process with the control chart implemented,
- A comparison of the plant performance with and without a control chart,
- A summary statement describing the effect of implementing a c control chart upon the quality (as measured by the benchmarks) of the Mouse Factory.

From the deliverables, a rubric was developed as show in Figure 4.

The final component of this laboratory is assessment. Student performance for this laboratory is evaluated using the rubric show in Figure 4. Students were voluntarily asked to complete a demographic sheet and survey after submitting the laboratory assignment. The survey focused on the students perceived understanding of the laboratory learning goals and confidence to implement learning goals in real life.

SPC Project 4 Rubric
Name:
Score:

Component	Exceptional (9 - 10 points)	Effective (8 - 9 points)	Acceptable (7 - 8 points)	Unsatisfactory (0.0 – 7.0 points)	Score
Explanation of Sampling Plan	A complete and detailed explanation of sampling plan	A thorough explanation of sampling plan	An adequate explanation of sampling plan	An incomplete or inaccurate explanation of sampling plan	
Control Chart Parameters (retrospective)	A complete, detailed and accurate explanation of control chart parameters	A thorough analysis of control chart parameters	An adequate analysis of control chart parameters	An incomplete or inaccurate analysis of control chart parameters	
Total Production Benchmark (with Control Chart)	A complete, detailed and accurate benchmark of the total parts produced	A thorough benchmark of the total parts produced	An adequate benchmark of the parts produced	An incomplete or inaccurate benchmark of the total parts produced	
Good Part Benchmark (with Control Chart)	A complete, detailed and accurate benchmark of the good parts produced	A thorough benchmark of the good parts produced	An adequate benchmark of the good parts produced	An incomplete or inaccurate benchmark of the good parts produced	
Bad Part Benchmark (with Control Chart)	A complete, detailed and accurate benchmark of the bad parts produced	A thorough benchmark of the bad parts produced	An adequate benchmark of the bad parts produced	An incomplete or inaccurate benchmark of the bad parts produced	
Offspec Part Benchmark (with Control Chart)	A complete, detailed and accurate benchmark of the offspec parts produced	A thorough benchmark of the offspec parts produced	An adequate benchmark of the offspec parts produced	An incomplete or inaccurate benchmark of the offspec parts produced	
Control charts for online data	A complete, detailed and accurate analysis of control charts for online data	A thorough explanation of control charts for online data	An adequate explanation of control charts for online data	An incomplete or inaccurate explanation of control charts for online data	
Before/after performance comparison	A complete, detailed and accurate comparison of production and quality performance	A thorough comparison of production and quality performance	An adequate comparison of production and quality performance	An incomplete or inaccurate comparison of production and quality performance	
Summary of Findings	A complete and detailed discussion of effectiveness of control chart for variables	A thorough discussion of effectiveness of control chart for variables	An adequate discussion of effectiveness of control charts for variables	An incomplete or inaccurate discussion of effectiveness of control chart for variables	
Report	Report is well-written, grammatically correct and free of spelling errors.	Report contains very few grammatical errors and misspelled words.	Some grammar and punctuation errors; report content is sometimes confusing .	Several grammar, spelling or punctuation errors; report is very difficult to read.	

Comments:

Figure 4. SPC Lab 4 Rubric

Results

The fourth SPC laboratory was implemented at the University of Texas – Pan American (UTPA) in MANE 4311 – Quality Control during the Fall 2011 semester. Sixteen students were enrolled in the course and eleven students completed the (voluntary) demographic information survey. Assessment results are provided in Tables 1-3.

Table 1 contains the student demographic information. Participation in the demographic survey was voluntary and only eleven students completed and submitted a demographic survey. The demographics are reflective of the UTPA student demographics. All students in this course were Hispanic. 55.6% of students reported a family income of $60,000 or less. An interesting statistic is that only 9.1% of the students responding had English as a first language. During the study period, there were more female students (54.5%) than male students.

Table 2 contains the evaluation of student performance. In general, students performed at a high level, either exceptional or effective. Students performed best at preparing control charts (retrospective), implementing control charts (online usage) and preparing benchmarks. Student performance was not as good on before/after comparison. Common mistakes in the before-after comparison section included not incorrectly implementing a test of hypothesis and not performing analyses for all four benchmarks (total parts, good parts, bad parts and offspec parts). These deficiencies were likely responsible for the relatively poorer performance in the summary of findings section.

Table 1. Student Demographics

Question	Response	Count
Gender		
	Male	5
	Female	6
Ethnic Group		
	Asian	0
	Black	0
	Caucasian (Non-Hispanic)	0
	Hispanic	11
	Native American	0
	Other	0
Family Income		
	$0 - $20K	2
	$20K - $40K	2
	$40K - $60K	1
	$60K - $80K	1
	$80K - $100K	2
	>$100K	1
English as first language		
	Yes	1
	No	10
GPA		
	<2.5	1
	2.5-3.0	3
	3.0-3.5	5
	3.5-4.0	2
Weekly Employment		
	<12 hours	4
	12 - 15 hours	1
	>15 hours	2
Marital Status		
	Single	11
	Married	0
Number of Children		
	0	11
	1	0
	> 1 child	0
Mother's educational achievement		
	Less than high school	0
	High School/GED	2
	Some College	2
	Two year college degree	1
	Four year college degree	3
	Master's degree	2
	Doctoral degree	0
	Professional degree (MD or JD)	1

Father's educational achievement		
	Less than high school	1
	High School/GED	0
	Some College	0
	Two year college degree	0
	Four year college degree	4
	Master's degree	3
	Doctoral degree	1
	Professional degree (MD or JD)	1
Current Enrollment		
	<12 hours	1
	12 – 15 hours	7
	> 15 hours	3

Table 2. Student Performance

Component	Exceptional (A)	Effective (B)	Acceptable (C)	Unsatisfactory (D-F)
Sampling Plan Explanation	7	2	1	3
Retrospective Control Chart	12	0	0	1
Total Parts Benchmark	5	7	0	1
Good Parts Benchmark	5	7	0	1
Bad Parts Benchmark	5	7	0	1
Offspec Parts Benchmark	5	7	0	1
Online Control Chart	10	0	0	3
Before/After Comparison	0	3	4	6
Summary of Findings	0	10	0	3

Table 3 contains the results of a student survey regarding the fourth SPC laboratory. Students were asked if the laboratory improved their understanding and confidence in ability to apply retrospective control charts, use control charts in an online mode and measure the impact of control charts on a manufacturing process. The results were very positive with no student responses of disagree or strongly disagree. Students were also asked if the laboratory should be used for future classes. 70% responded that they strongly agreed the laboratory should be used in future courses and 100% responded either strongly agree or agree that the lab should be used in future courses.

Analysis

An important issue in developing learning materials is robustness towards the demographic factors. That is that the level of performance is not influenced by demographic factors such as race, gender, family income or other factors. To determine if the level of performance and student survey responses are independent of the demographic factors, a series of tests for independence based upon contingency tables were conducted. These tests resulted in some large contingency tables (as indicated by the degrees of freedom). With only eleven demographic

responses, many cells in some of the tables are below recommended sample sizes. Therefore these results are extremely preliminary and the validity of the tests will improve with larger sample sizes.

Table 3. Student Survey

Component	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Improved understanding of retrospective *c* control chart	3	6	1	0	0
Improved confidence of retrospective *c* control chart	5	4	1	0	0
Improved understanding of online usage of *c* control chart	5	3	2	0	0
Improved confidence of online usage of *c* control chart	3	6	1	0	0
Improved understanding of impact of *c* control chart	4	4	2	0	0
Improved confidence of impact of *c* control chart	3	5	2	0	0
Recommend lab 4 for future classes	7	3	0	0	0

Table 4 displays the analysis of the fourth SPC laboratory performance versus demographic factors. Seven demographic factors and eight performance factors were considered requiring fifty-six contingency tables to be evaluated. Values of the Chi-squared test statistic, degrees of freedom and p-value for each contingency table are displayed. Only three contingency tables were statistically significant at either the .05 or .10 level of significance. The first statistically significant test was gpa versus the sampling plan explanation. The second statistically significant test was gpa versus online control chart and the final statistically significant test was enrollment versus enrollment. In general, these demographic factors reflect either a student's prior academic performance (gpa) or a student's workload (enrollment) and do not indicate embedded biases due to demographic factors such as gender, race, family income or family educational levels.

Table 5 displays the analysis of the student surveys versus demographic factors for SPC lab four. Seven demographic factors and seven survey questions were examined requiring forty-nine contingency tables to be evaluated. Values of the Chi-squared test statistic, degrees of freedom and p-value fore each contingency table are presented. Seven tests were statistically significant at either the .05 or .1 level of significance. The statistically significant tests are:
- Understanding of retrospective use of *c* chart versus gender,
- Understanding of retrospective use of *c* chart versus employment,
- Understanding of retrospective use of *c* chart versus mother's educational level,
- Understanding of online use of *c* chart versus father's educational level,
- Recommend for future use versus gender,
- Recommend for future use versus employment, and
- Recommend for future use versus mother's educational level.

These statistically significant tests indicate potential demographic factors that have a relationship with students' perceived expertise and recommendation for future usage. The sample size in this survey is much too small to derive meaningful results. However, these relationships will be investigated more thoroughly when the sample size is larger.

Table 4. Analysis of Lab 4 Performance versus Demographic Factors

Lab 4 Metric		Demographic Factors						
		Gender	Income	GPA	Employment	Mother Educ.	Father Educ.	Enrollment
Sampling Plan Explanation	Test Statistic	4.086	15.300	**15.426**	2.778	25.619	9.690	2.020
	df	3	15	**9**	4	15	15	6
	p-value	0.252	0.430	**0.080***	0.596	0.042	0.839	0.918
Retrospective Analysis	Test Statistic	1.320	3.938	2.883	1.143	2.933	1.925	0.629
	df	1	5	3	2	5	5	2
	p-value	0.251	0.558	0.410	0.565	0.710	0.859	0.730
Total Parts Benchmark	Test Statistic	0.782	6.975	5.084	1.333	4.278	4.278	1.397
	df	1	5	3	2	5	5	2
	p-value	0.376	0.223	0.166	0.514	0.510	0.510	0.497
Good Parts Benchmark	Test Statistic	0.782	6.975	5.084	1.333	4.278	4.278	1.397
	df	1	5	3	2	5	5	2
	p-value	0.376	0.223	0.166	0.514	0.510	0.510	0.497
Bad Parts Benchmark	Test Statistic	0.782	6.975	5.084	1.333	4.278	4.278	1.397
	df	1	5	3	2	5	5	2
	p-value	0.376	0.223	0.166	0.514	0.510	0.510	0.497
Offspec Parts Benchmark	Test Statistic	0.782	6.975	5.084	1.333	4.278	4.278	1.397
	df	1	5	3	2	5	5	2
	p-value	0.376	0.223	0.166	0.514	0.510	0.510	0.497
Online Control Chart	Test Statistic	0.000	6.825	**8.625**	1.440	7.500	3.600	3.000
	df	1	5	**3**	2	5	5	2
	p-value	1.000	0.234	**0.035****	0.487	0.186	0.608	0.223
Comparison	Test Statistic	1.253	12.000	6.081	1.333	8.708	10.771	2.008
	df	2	10	6	4	10	10	4
	p-value	0.535	0.285	0.414	0.856	0.560	0.376	0.734
Summary	Test Statistic	2.037	3.938	4.074	1.143	7.741	4.278	**11.524**
	df	2	5	6	2	10	10	**4**
	p-value	0.361	0.558	0.667	0.565	0.654	0.934	**0.021****
* values are statistically significant at the 0.1 level, ** values are statistically significant at the 0.05 level								

Table 5. Analysis of SPC Lab 4 Student Survey versus Demographic Factors

Lab 4 Survey Question		Demographic Factors						
		Gender	Income	GPA	Employment	Mother Educ.	Father Educ.	Enrollment
Understanding – retrospective c chart	Test Statistic	0.747	2.400	5.8000	5.556	13.200	10.400	4.480
	df	2	6	4	4	8	6	4
	p-value	0.688	0.879	0.215	0.235	0.105	0.109	0.345
Confidence – retrospective c chart	Test Statistic	**4.800**	2.000	7.500	**10.000**	**13.667**	9.000	1.667
	df	**2**	3	4	**4**	**8**	6	4
	p-value	**0.091***	0.572	0.112	**0.040****	**0.091***	0.174	0.797
Understanding – online c chart	Test Statistic	1.600	9.500	2.000	5.556	9.000	5.000	3.200
	df	2	6	4	4	8	6	4
	p-value	0.449	0.147	0.736	0.235	0.342	0.544	0.525
Confidence – online c chart	Test Statistic	0.747	2.400	5.600	5.556	13.200	**11.800**	4.480
	df	2	3	4	4	8	**6**	4
	p-value	0.688	0.494	0.231	0.235	0.105	**0.067***	0.345
Understanding – impact of c chart	Test Statistic	2.311	5.500	5.333	6.730	10.000	8.667	3.200
	df	2	6	4	4	8	6	4
	p-value	0.315	0.481	0.255	0.151	0.265	0.193	0.525
Confidence – impact of c chart	Test Statistic	1.600	8.250	4.500	5.556	10.000	8.000	4.200
	df	2	6	4	4	8	6	4
	p-value	0.449	0.220	0.343	0.235	0.265	0.238	0.380
Recommend future usage	Test Statistic	**2.880**	3.750	0.533	**5.000**	**8.000**	3.733	0.747
	df	**1**	3	2	**2**	**4**	3	2
	p-value	**0.090***	0.290	0.766	**0.083***	**0.092***	0.292	0.688

* values are statistically significant at the 0.1 level,
** values are statistically significant at the 0.05 level

Conclusions

In general, students performed well on the fourth SPC laboratory. They also responded favorable that the use of the laboratory improved their understanding and confidence in performing tasks associated with the *c* control chart. Students also indicated that the laboratory should be used for future classes.

Future Research

The most pressing need is to increase the sample size to improve the validity of the contingency tables. Once reasonable sample sizes are collected, the contingency table analysis will be repeated and associations between statistically significant tests for independence between demographic factors and performance levels/survey responses will be investigated in-depth. Readers interested in participating in this research should contact the lead author.

Acknowledgements

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