
AC 2012-3393: ASSESSING THE VIABILITY OF BENCH TOP VERSUS FULL-SCALE INDUSTRIAL LATHES TO TEACH FUNDAMENTAL MACHINING CONCEPTS

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“Assessing the viability of bench-top versus full scale industrial lathes to teach fundamental machining concepts.”

Abstract

Maintaining quality technology, manufacturing, or engineering programs requires institutional support, dedicated faculty and students, and specialized equipment to provide immersive experiences. However, the cost of updating or replacing outdated and unsafe equipment presents a unique challenge for educational institutions faced with stagnant or decreasing budgets. Doing more with less has become the mantra of leaders at the national, regional, and local levels but how to accomplish this presents a dilemma for academicians at all levels. Manufacturing program typically utilize a wide variety of industrial equipment that run the gamut from automated to manually operated systems. Further, these units not only require large spaces in buildings, they are also costly to operate and maintain. Faced with these challenges, institutions will have to adapt and innovate by pursuing alternative and creative approaches to educating 21st century students. Two issues were examined in a recent study: 1. To ascertain the extent to which less costly bench-top metal lathes can be used as viable alternatives in provide students with an understanding about the design and creation of manufactured items And 2. Determine the levels of acceptance by faculty and industry about the use of smaller lathes as viable alternatives to their industrial size cousins. A study was conducted into the use of bench-top metal lathes in a post-secondary educational institution. A metal lathe was chosen for this study primarily due to its multipurpose nature and ability to provide hands-on experiences in a variety of applications, e.g. milling, drilling, and grinding. The results of the study demonstrated that there were no significant differences in tolerances achieved from bench-top metal lathes when compared to their large scale industrial cousins. In addition, faculty and industry's acceptance suggests that bench-top metal lathes are acceptable substitutes to full size lathes in the laboratory settings.

Introduction

Preparing 21st century students for the workplace requires competent educators knowledgeable about industrial practices and also access to available equipment to provide needed experiential learning. Additionally, since students must be taught the fundamental concepts associated with manufacturing practices, it is important to utilize a variety of specialized tools to implement product designs. However, the ability of institutions to meet these goals in fiscally austere times is proving to be difficult for all but those with the financial resources to acquire costly industrial grade equipment.

In order for manufacturing and vocational programs to survive, they must adapt and become cost conscious. And, when cost-saving measures are necessary, it is important to ensure that the program will still satisfactorily prepare students to enter the job-market as qualified workers. While it may not be necessary for graduates in some program areas like engineering to demonstrate proficiency in the use of specialized manufacturing equipment, it is nonetheless important that students in many related disciplines have an understanding about product design and manufacturing process operations if they are to be regarded as credible, particularly if they will be supervising or working with others in any design or production activity.

It is reasonable to assume that automation in modern manufacturing industries has all but eliminated the need for certain skills or abilities by employees. However, this attitude is

inconsistent with findings of a study by the University of California at Berkeley¹ and another study conducted by Deeter,² who suggests the necessity for students to first have a solid foundation in manual process if they are to effectively learn how to use Computer Numerical Controlled (CNC) equipment. The issue facing program directors, therefore, is a complex and multifaceted one where they may have to deal with the matter of cost containment while at the same time ensuring quality educational experiences for all students.

Much has been written about manufacturing technology educational programs, however, no studies were found using a variety of databases (ERIC Educational Database, Academic Search Premier, Elsevier Science Direct, and other sources found on the World Wide Web) about small scale equipment use in lieu of costly industrial size models. From a practical perspective, it seems reasonable to assume that smaller machines could provide experiences comparable to those obtained from using larger systems, but to what extent would bench-top lathes be capable of producing tolerances consistent with large scale industrial systems? Understanding the nature of manufacturing practices—procedural and technical—is essential to technology or industrial technology programs at the secondary and post-secondary levels. Therefore, care must be taken to ensure that any substitution of equipment will produce comparable experiences for students. This paper examines two issues arising from a study of metal lathes: 1. the use of less costly manufacturing equipment—a bench-top lathe—to provide students with some understanding about what goes into the design and creation of manufactured items; and 2. faculty and industry' acceptance of smaller lathes as viable alternatives to their costly industrial size cousins. The metal lathe was selected for this study because of its multipurpose nature and the capability of the unit to provide hand-on experiences in a variety of manufacturing applications, e.g. milling, drilling, and grinding.

Historical Perspective

The Industrial education roots can be traced to ancient times where a need existed to educate workers in the performance of various tasks essential for work. And, according to Bennett,³ industrial education in America reflected the needs and values of an ever-changing world where fathers provided industrial education for their sons at a time when it was possible for sons to learn what they needed to know about a trade.⁴ Eventually this father-son system of training evolved into apprenticeship programs that were responsible for the bulk of technical training in the 18th and part of the 19th centuries in the United States. Later, the Morrill Act of 1862 helped establish Land Grant Colleges in each state to educate students in agriculture and mechanical arts. This singular act was a pivotal point in the history of American education and enabled industrial education to become a more common and widely accepted part of higher education in America.⁵ Although agriculture was considered the primary focus of the Morrill Act, it was in fact the engineering programs that were the norm at many of the land grant colleges.⁶ Engineering programs and industrial education shared common traits at the time, and it was not unusual to see elements of the engineering curriculum worked into an industrial education programs.⁷ However, what the Morrill Act did was to reflect the changing views of the time about what education should be and what it should include. By delineating the nature of the colleges established under the act, the Morrill Act also moved the American system of higher education one step closer to industrial education as it is known today.

The past methods of providing industrial education and the type of education that resulted from the Morrill Act strongly influenced the current state of industrial education in institutions of higher learning in America. The influence of earlier apprentice programs, which provided young people with an education that prepared them to become gainfully employed in a trade, seems to be evident in the values and views of modern day industrial education programs, particularly those in community colleges. Indeed, it may not be a stretch to suggest that many programs in colleges and universities still see value in “hands-on” or “experiential learning,” a desired feature of the modern curriculum.

Current Challenges Facing Technology Programs

Given the high cost associated with using and maintaining industrial equipment,⁸ many schools have begun replacing existing laboratories with newer modular laboratories. These units, while economically viable, have drawn criticism from some concerning their suitability to teach problem-solving skills.⁹ Many modular labs are organized in such a way that all students really have to do is read and follow directions to complete the necessary requirements for a given module.¹⁰ An example of a modular lab would be a Virtual Machine Shop¹¹ that is assessable to educators who no longer have easy access to physical machine shops which are traditionally part of manufacturing programs in education.

Virtual machine shops provide only one aspect of the educational experience—the opportunity to examine video clips of lathes in operation and learn about issues such as cutting tool geometry¹²—however, this approach lacks the valued and needed hand-on reinforcement experiences. Such were the findings of a study conducted by the University of California at Berkeley¹ where it was thought that a need existed for more hands-on approaches, especially in using manual machine tools. Similar views were expressed by instructors at Miami Valley.² While modern technology allows for the utilization of virtual environments to teach machine shop concepts—virtual machine shop¹²—there is the possibility that students may not acquire the same skills-sets (knowledge and abilities) in these environments as they would with traditional methods of instruction.⁸ Additionally, in some virtual environments, e.g. Second Life, there is the added possibility of personal and institutional liability if students are exposed to content that they find emotionally harmful.¹³

In 1992, researchers at the University of California (UC Berkeley) conducted a study of 45 individuals working in manufacturing to determine what educational requirements were needed for programs wishing to train students who would be pursuing jobs in this industry. The participants included machine operators, traditional setup machinists, CNC programmers, and industrial engineers. Results of the study indicated a perceived need for more hands-on approaches in education, particularly those dealing with the instruction of manual machine tools. Many of the machinists interviewed for the study felt that CNC machines would never entirely replace manual machines in the workplace because these machines were too inflexible for the many individual tasks required in a manufacturing environment. Machinists who were interviewed also indicated that understanding the CNC machines and their operation required a solid foundation in manual machine tool operation. This sentiment was also supported by the industrial engineers in the study who felt that it was necessary to learn manual machine tool operation before venturing into the subject of CNC machines.¹

The UC Berkeley study also identified some related issues about current educational practices. For example, many technology programs were either eliminated^{12, 14}, or began switching to different curriculums, such as modular laboratories,¹⁵ because of the expenses associated with maintaining traditional machining programs.⁸ Simply increasing class sizes—one way to generate needed revenue—may not only increase student-to-faculty ratios but also the number of students that can be served by the available equipment. One important finding in the UC Berkeley study was that CNC equipment is perhaps less important than having simpler manual machine tools that have traditionally been part of these programs.¹ Given the cost of new industrial equipment—manual or programmed—a reasonable alternative may be to obtain used systems. However, securing older equipment presents three issues: frequent repairs, obtaining replacement parts, and the need to add the safety features found in newer equipment. Faced with these issues, bench-top machine tools might become a suitable option for addressing safety concerns and costs, while still providing students with working-world experiences.

Cost concerns and the resulting impact

Concerns about the cost of running industrial technology programs are not lost on educators who recognize the expenditures associated with maintaining and operating technical programs. Rawlins, president of Washington State University, noted that “technology programs are easy targets for cuts because they are expensive”⁸ with Rogers¹⁶ placing the value of maintaining one modern industrial technology education laboratory at somewhere around \$500,000 in 1996 dollars.^{17, 8, 16} However, while the cost of equipment is likely to change over time, it is not expected that these changes will be significantly different from year to year. Furthermore, while manual machines can be used for many years with minimal updates, CNC machines can quickly become outdated with updates becoming increasingly expensive. Therefore, it is not surprising that higher operating programs will come under close scrutiny when attempting to balance budgets at the program and institutional levels.

A report on a national survey of state practices conducted in 2000 and submitted to the Ohio Legislative Office of Educational Oversight noted that the cost to purchase and maintain vocational instructional equipment has been a leading factor in the relatively high expenditures of vocational education.¹⁸ While there may be creative ways to address cost-related issues, the temptation to equip machine shops with older equipment, obtained through donations or other means, may not be a desired solution to the problem. Most modern equipment are required by OSHA to have certain minimum safety features, many of which are lacking in older machines. The lack of these features can result in hazardous situations for the student¹⁹ thereby leaving the institution liable in the event of injuries associated with any accident. Even if the existing equipment can be updated to an appropriate safety level, the lack of relatively inexpensive available replacement parts is often an issue. How then should directors of manufacturing program deal with the huge cost associated with equipment procurement and maintenance? This study was designed to address this very issue.

Methodology

The methodology employed in this study was designed to obtain data to answer the two research questions: 1. to what extent can less costly bench-top metal lathes be used as viable alternatives

to provide students with an understanding about the design and creation of manufactured items? And 2. what are the levels of acceptance by faculty and industry personnel about the use of smaller lathes as viable alternatives to their industrial size cousins? A survey was developed to answer questions 1 and 2 and a pilot study was conducted to provide comparison data for question 2 relative to the tolerances that could be achieved when manufacturing an aluminum stock on both the industrial and bench-top lathes.

The population for the faculty portion of this study consisted of professional members of the Association of Technology Management and Applied Engineering (ATMAE). A total of 515 surveys were sent to all of the professional members. The population for the industry portion of the survey was an upper mid-western university technology department alumnus, and the survey instrument was sent to the entire population, a total of 435 individuals. Although sampling the entire populations of ATMAE and technology alumni from an upper mid-western university took a significant amount of time, it was one way to eliminate the problems of sampling error. In addition, since response rates are often low, having the maximum sample size at the beginning improved the researcher's chances of receiving an acceptable level of participation.²⁰ A branching or adaptive feature in the electronic survey allowed respondents to skip questions if respondents did not have the necessary background or experience to properly answer specific questions.

The designed instrument collected demographic information related to gender, employment history, and educational level achieved. Faculty and industry personnel perceptions concerning the suitability of bench-top metal lathes were also collected and analyzed, including study participants knowledge of metal turning lathes and their prior experiences. Two lathes—bench-top and industrial sized devices—with similar features were utilized in this study.

Pilot Study

For the pilot study, two graduate students created a bushing similar to those created by students in an introductory machining course taught at the university where the study was conducted. Each graduate student turned 15 bushings on both a Cummins 7"x12" bench-top metal lathe and also a 13"x 24" Clausing industrial lathe, for a total of 60 bushings. The number of samples selected was determined by time limitations and historical enrollment numbers for the manufacturing class, which typically has around 30 students. Each bushing was measured in 3 different areas:

1. outside diameter;
2. step diameter;
3. step length.

The samples selected, because of their high machinability index and also commercial availability, were all turned from 6061 aluminum. The spindle speed on both lathes used in the study were calibrated using a digital laser, non-contact tachometer, and the spindle speed was adjusted to 1200 rpm, the upper limit for the Clausing industrial lathe. A TT style C2 grade carbide tool insert was installed in a holder that both lathes could accommodate. During the study the insert was replaced after every sixth part to reduce the effects of tool wear on the

process. Every attempt was made throughout the course of this study to keep the setup the same for both machines. Spindle speeds were checked once during each test period, and the variable speed dial was clearly marked with the appropriate position for the correct speed setting. In addition, a template was created to allow the tool post to be set to a uniform angle of approach, and this angle was matched to the other lathe. Feed settings were adjusted to match both machines as closely as possible and these settings were also confirmed during each test period. These procedures were particularly important to follow since it was impossible to produce all of the bushings at the same time. Due to these circumstances it was therefore necessary to follow the above mentioned procedures to reduce the possibility that settings on either machine could change, thereby resulting in differences between the two machines that might skew the data.

Validity and Reliability

To ensure the content validity of the questionnaire, a representative sample from the two populations (faculty, and industry) were asked to look at the questionnaire and comment on the clarity and content of the questions, written directions, cover letter, formatting and layout. These responses were used to determine whether the survey instrument was an appropriate length and was internally valid. The reliability of the three component sections of the Likert-scale portion of the questionnaire was determined following the pilot study using Chronbach alpha values and the responses from the pilot study.

Data Collection and Preparation

Data collection for the faculty and industry portion of the study involved a one-time response to a three-part (Faculty) and two-part (Industry) questionnaire that required approximately 15-20 minutes to complete. Questionnaires were first viewed to identify any inconsistencies or missing data. Responses with missing information are generally not considered valid for statistical analysis,²¹ and consequently those responses were not included in this study. Data preparation included data coding, data entry, and verification. To assure that data had been entered correctly, every fifth questionnaire was checked for errors once all the data entry was completed.

Data Analysis

Analysis of the data for this study required the use of descriptive statistics and Pearson correlation statistical tests. A multivariate analysis of variance was used to determine the differences between the criterion variables and demographics. And, the laboratory pilot study was analyzed using either standard t-tests, or a Mann-Whitney Wilcoxon test for non-normal distributions. Microsoft Excel and Statgraphics Centurion XVI for Windows were also used for all statistical calculations.

Data Interpretation

The first research question in the study addressed the use of a less costly piece of manufacturing equipment to provide students with some understanding about what goes into the design and creation of manufactured items. One area of concern in conducting this study centered on the durability of the smaller, lighter bench-top lathe as compared to the heavier, industrial style lathes. The faculty who responded to a question largely felt (67.6%) that if the material (the work

piece) were adjusted to suit the size of the machines, the bench-top lathes would be durable enough to work in educational environments. Some faculty were unsure about the question of durability (20.1%) and 12.2% felt that the durability would be a concern in the use of bench-top metal lathes in educational settings. While many believe that bench-top lathes are less durable than their industrial counterparts, it is possible that with proper, routine, maintenance, such equipment may be adequate in a laboratory setting to teach machining processes. Therefore, any decision to adopt bench-top lathes will need to be carefully weighed against the additional maintenance that might be required when using these lathes.

Modifications to the Curriculum

Industry and faculty were asked whether they would be open to changing the curriculum taught in traditional programs to accommodate the smaller sizes of bench-top metal lathes. The majority of individuals surveyed (90.6% of those from industry and 73% of faculty) believe course content can be adjusted to accommodate the smaller material sizes that are necessary when using bench-top lathes without presenting adversely affecting student learning. Furthermore, 77% percent of faculty and 77.9% of industry participants agree or strongly agree that if students were taught speeds and feeds in both theory and laboratory experiments, it would not matter whether students were performing the laboratory test on a 1" diameter stainless steel bar or a 10" diameter bar of the same alloy. Though the response overall was in favor of using smaller material quantities, some faculty (23%), felt that teaching machining on a small scale level would not be as effective as if students completed the task on large diameter materials.

Some faculty place more emphasis on teaching and less on research, or vice versa, and their response to survey items may be indicative of the differences in the teaching experiences of those who felt teaching machining on a small scale would be as effective versus those who felt it would not be as effective. However, the money saved by working with smaller quantities of materials is difficult to ignore. Given the cost of ferrous and non-ferrous metals, which fluctuates wildly, it is difficult to know whether material costs are going to prove cost prohibitive for many educational institutions since they certainly represent a huge unknown cost to programs. Smaller quantities of materials can be stockpiled much easier than large quantities, and they do not require specialized equipment to move materials or stock into location where it can be processed by the machine. Further, when a student makes a mistake on a smaller quantity of material, the loss is not going to be as great compared to the same mistake being made on a larger, more costly piece. Some of the respondents who felt using smaller equipment would not be as effective might have been thinking about the situation more from a research perspective where having tools that hold high tolerances might be crucial to the work that an educational institution may be attempting to do. In those instances, bench-top machine tools, at least those at the lower end of the price range, would probably not prove suitable.

Suitability for Industrial Employees

A majority (80.9%) of individuals in industry who responded to the survey replied in the affirmative to the statement "It is important for employees in your company who are hired with degrees in industrial technology degree to have a basic understanding of machine processes." An even larger percentage (89.5%) believe students who have been trained to use manual machine

tools should have a better foundation for learning about computer numerical controlled (CNC) machine tools. This viewpoint is consistent with the findings of the UC Berkeley study, which found that manual processes are an important foundation for anyone learning about CNC operation.¹

Not surprisingly, considering the previously expressed views, 79.5% of those from industry indicated that those with hands-on experience will be better employees for their companies, and 91.5% of participants who were surveyed from industry believe technology programs need to continue teaching machining concepts with a portion of the curriculum offering a hands-on approach. Though the two response percentages were relatively close, there is some question as to why there is a 11% difference concerning the needs for programs to continue teaching hands-on elements and the rift between whether employees that received hands-on training will prove more beneficial to a company's needs. It could be that the 11% gap is coming from companies that are doing work that is outside of the realm of the rest of the field. Perhaps these employers agree that for the most part hands-on curriculums might be a good idea and that it may work for a wide range of careers; however, they do not necessarily see benefits in their specific company or area within a company. For example, some who completed the survey may work in areas where management is overseeing activities that does not involve machining.

Safety Concerns

There were some differences in how participants viewed the factor of safety with regards to the substitution of bench-top lathes for industrial lathes in educational settings. Faculty, for instance, have divided opinions concerning the impact of a lack of certain safety features on bench-top lathes and what this may mean for their suitability in educational settings, as 46.6% view the lack of a brake as a concern while only 13.6% did not feel it was. The remaining 39.8% were unsure if it is an issue. In some ways this question might be misleading, as the bench-top lathes used in this study have a paddle switch that will cut power to the entire system as quickly as an operator can apply the brake in a conventional lathe. The brake on most lathes is simply a mechanical override that stops the spindle motion while the motor continues to run. Because the brake is mechanical, it is subject to the same wear and tear as the brake pads on an automobile, which without routine maintenance can become worn and ineffective.

Faculty were not asked if they have concerns about design issues with the industrial lathe because it was expected that not all of the faculty surveyed would have had experience with the specific lathes being used by the students for the study. However, despite their (faculty) belief that students might be less intimidated by the bench-top lathe, only 35.6% of the faculty believe that substituting bench-top lathes for industrial lathes would make the classroom safer. This is a somewhat surprising response, but perhaps many faculty do not believe that there is a correlation between a student's level of comfort with lab equipment and its effect on lab safety. Close to half (45.2%) are not sure if the substitution would impact safety, while 19.2% believe the substitution would not make the classroom safer.

Responses pertaining to the second research question

For the second research question, faculty and industry acceptance of smaller lathes as viable alternatives to their industrial size cousins was explored. The ability of the smaller bench-top lathes to perform accurate work was explored in the pilot study. It would appear, based on the results from this limited pilot study, that both the bench-top and the industrial lathes are capable of producing test bushings within the specified .005” tolerance range. It should be noted, however, that this pilot study was the result of tests done by only two graduate students, and an expanded study utilizing a much larger cross section of technology students would be necessary to determine whether the initial findings could be replicated. Tables 2, 3, and 4 show the summary results of the pilot study.

Table 2. Pilot Study Findings

	Bush Outside Diameter Clausing Industrial Lathe	Bush Outside Diameter Cummins Bench-top Lathe
Count	30	30
Average	0.351	0.350
Standard deviation	0.003	0.002
Minimum	0.343	0.347
Maximum	0.355	0.353
Range	0.012	0.006
Std. Skewness	-1.934	-0.139
Std. Kurtosis	0.736	-1.148

The above data in Table 2 for the outside diameter of the bushings indicated that both the standard skewness and standard kurtosis values were within the range of -2 to +2, which indicates that the samples come from normal distributions. A t-test was then conducted to compare the means of the two samples, and it was found that the difference between the two means extends from -0.001 to .002. Since the interval contained the value of 0, it was determined that there was not a statistically significant difference between the means of the two samples at the 95% confidence level.

Table 3 shows the results of the same experiment done with the Clausing industrial lathe and with a Cummins bench-top lathe. Table 4 shows step length data. Data taken from the step length was found to have more variance than the other two groups. This data did show departures from normality for both the bench-top and industrial lathes. Because this data did not come from normal distributions, it was not possible to run a standard t-test. For this particular group a Mann-Whitney Wilcoxon test was performed because this test does not require normal distributions. The results of this test indicated that there was not a statistically significant difference between the two data sets at a 95% confidence interval.

Table 3. Summary Statistics.

	Clausing Industrial Lathe Step Diameter	Cummins Bench-top Lathe Step Diameter
Count	30	30
Average	0.313	0.313
Standard deviation	0.002	0.002
Minimum	0.308	0.308
Maximum	0.318	0.318
Range	0.01	0.01
Std. Skewness	-0.059	-0.539
Std. Kurtosis	-0.385	0.112

Table 4. Summary Statistics.

	Clausing Industrial Lathe Step Length	Cummins Bench-top Lathe Step Length
Count	30	30
Average	0.237	0.237
Standard deviation	0.010	0.008
Minimum	0.213	0.208
Maximum	0.253	0.256
Range	0.04	0.048
Std. Skewness	-2.065	-3.117
Std. Kurtosis	-0.183	2.612

Suitability to Task

Determining the extent to which bench-top lathes can be used as suitable replacements for industrial lathes was one of the goals of the study. An analysis of data from the pilot study indicated that there were no significant differences in the tolerances achieved on manufactured parts produced by the bench-top and industrial lathes. Once it was determined that bench-top metal lathes were capable of producing precision parts, it then became necessary to ascertain the extent to which industry and faculty would be accepting of the use of this equipment as a suitable replacement for traditional industrial lathes in education setting. The majority of individuals surveyed— 87.5% of faculty and 89.5% of industry— agreed that bench-top metal lathes, when properly used in the curriculum, would be capable of teaching the same fundamental concepts in metal turning (such as facing, turning, and drilling) when compared to larger industrial lathes.

In response to a related survey statement, “It is essential for students who might be future employees of your company to be trained on the same machine tools used in your company,” 74.4% of respondents in industry agreed with the statement. Clearly, employers would prefer that those they employ have experience with equipment that exists in the work environment. However, this may not always be possible in educational settings due to many constraints, one of which may be related to procurement and maintenance cost of industrial equipment. If it is determined that an understanding of manufacturing processes is essential, which it is for some technology or industrial technology programs, then bench-top lathes may be a viable alternative for such programs attempting to reduce cost expenditures.

Decision to Purchase Bench-top or Industrial

When asked the question about whether an institution should purchase ten bench-top metal lathes or two industrial lathes, 39.2% of the faculty favored the purchase of ten bench-top lathes rather than two industrial lathes. Thirty-seven percent of the faculty responded that an institution would fare better purchasing two industrial lathes, and about 23% were unsure what the best course of action would be. It is probably not too surprising that respondents differed in their views concerning how funds should be allocated for equipment. While the results of the machined items produced similar results, thereby suggesting that bench-top lathes are a viable alternative, other factors besides costs might warrant some consideration. Programs sometimes have existing equipment that is either in a state of neglect or simply outdated. Existing equipment should be assessed for their capability to teach key constructs in the curriculum. Additionally, the number of students a program is attempting to serve, size of the existing facility and its physical structure (some buildings are not strong enough to take the weight load of large equipment), electrical service considerations, ventilation systems, and type of work that the program wishes to produce, including available resources poses unique challenges to program areas. Any these factors can influence and impact decisions that an institution may make concerning the adoption of bench-top machine tools because there is no one-size-fits-all solution.

Equipment clearly matters in secondary and post-secondary environments where it is necessary for students to gain some understanding about the fundamentals of manufacturing processes, including how to use selected tools such as mills, lathes, and CNC machines to produce a desired item. Where this is the case, then the focus should be on ensuring that students are taught the essentials. It is always tempting to chase after new equipment; however, consideration has to be given to the degree to which current tools can adequately accomplish a desired task. Tools are only as good as the individuals using them and educators should not be lulled into thinking that tools are an adequate substitute for poor teaching. Competent educators, who focus on teaching and learning, should not only be able to help students understand the relevant theories shared in the classroom, they should also work to ensure that students are able to demonstrate proficiency in applying the theories to solve a variety of problems using selected tools. Ultimately, what is important is that students acquire the necessary knowledge and skills that will enable them to demonstrate in tangible ways what they know, understand, and can do as a result of what was shared with them in the classroom.

Conclusion

Any decision to identify equipment alternatives has to take many factors into consideration and should be approached with careful consideration to how selected equipment will accomplish the desired effect—improving teaching and learning. This study demonstrated, based upon an analysis of a pilot study data, that bench-top lathes can be considered as viable alternatives to their industrial sized cousins. Similarly, an analysis of the responses from faculty and industry suggest that bench-top lathes are a viable alternative to larger industrial lathes. Bench-top lathes, because of their size, have limitations, such as reduced capacity and less rigidity, thereby restricting the size materials that can be produced by these lathes. However, because of material costs, it may be more appropriate for students to work on smaller projects in educational settings.

Finding ways to continue to educate students using effective pedagogical practices and preparing them for various field of work may require some creative thinking in a time of fiscal constraints. Vocational programs need to be cost effective if they are to survive. However, cutting costs at the expense of the quality of programs—this includes a focus on teaching and learning as much as it includes equipment—does not seem to be an acceptable solution. The results of this study, based, on an analysis of the machined parts, suggest that using bench-top lathes in educational settings may provide a more cost-effective alternative to industrial lathes without impacting the quality of programs. And, according to participants in this study, using bench-top lathes also seems to be a viable option that will still allow programs to provide the necessary experiential learning.

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