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A Framework for Leveraging the Senior Design Sequence for Laboratory Development in a Mechanical Engineering Technology Degree Program

Kevin M. Hubbard, Missouri State University; Martin P. Jones, Missouri State University; Richard N. Callahan, Missouri State University

Abstract

Problem-based learning projects are an extremely effective tool with which to encourage engineering and engineering technology students to synthesize knowledge gained in previous coursework, think entrepreneurially, and evaluate design tradeoffs to reach optimum solutions. However, difficulties with regard to project implementation may often be encountered as a result of the resource-limited environments in which many engineering and engineering technology programs currently operate. In this paper, the authors present a formal methodology for project selection as well as an algorithm by which to evaluate the leverage, or amplification, of derived benefit, which may be realized as a result of the implementation of these projects. A capstone project leveraging index was formulated that accounts for both financial benefits and subsequent student academic benefits. A case study of the use of this method is also presented.

Introduction

For many institutions of higher education, budgets have not kept pace with cost increases over the past decade (Vrielink, Jansen, Hans, & van Hillegersberg, 2017). Many engineering and engineering technology programs are under increasing pressure to do more with less (Feisel & Rosa, 2005). Equipment maintenance and acquisition budgets are often particularly hard hit. However, laboratory instruction plays a vital role in engineering and engineering technology education (Feisel & Rosa, 2005). Problem-based learning projects are a valuable tool with which to encourage students to synthesize the knowledge gained in several courses (Liu, Mynderse, Gerhart, & Arslan, 2015). Additional benefits gained through the use of problem-based learning projects include the fostering of the students' ability to iteratively refine engineering designs, and to apply a systems-based approach for the solution of complex, ambiguous design problems, such as those typically encountered in an industrial environment (Liu, Mynderse, Gerhart, & Arslan, 2015). In addition, project-based hands-on learning is highly valued by many students (Esmaeili & Eydgahi, 2014). The senior capstone design course in the Mechanical Engineering Technology program at Missouri State University employs a problem-based learning project and is intended to facilitate the development of these types of characteristics in students who are about to graduate.

The juxtaposition of these two sets of priorities—the need to provide problem-based learning projects and the necessity of operating in a limited-resource environment—presents an opportunity to leverage internal resources. Senior design sequences may be used to alleviate the budgetary pressures associated with laboratory development. In this way, student and faculty efforts may be leveraged and the laboratory instruction experiences of subsequent students in other courses throughout the curriculum may be enhanced, even in a limited-budget resource environment. In this paper, the authors present a framework through which laboratory development projects may be selected and implemented in the senior design sequence and the leveraging effects associated with the implementation of these types of projects may be measured. The enumeration of these leveraging effects may be used in internal benchmarking and for accreditation purposes. A case study based upon the selection and implementation of a laboratory development problem-based learning project in the senior capstone course of the Mechanical Engineering Technology program at Missouri State University is presented.

Factors Influencing Project Selection

Project-selection processes will typically be influenced by a number of factors. These factors often include:

- The program outcomes that the senior design capstone sequence is intended to address: Common capstone course outcomes include the ability to perform professionally, produce quality design products, perform effectively in a team setting, perform project management tasks effectively, perform creative and effective problem solving, perform knowledge synthesis effectively, and communicate effectively (Davis, Beyerlein, Thompson, Gentili, & McKenzie, 2003).

- The types of skills desired by employers of graduates of the program: The skills developed by students in project completion should be relevant to the needs of industry and, in particular, to the needs of the potential employers of those students. Industrial relevance is one of the most critical objectives in curriculum design (Cecil, 2004).

- The desired amount of synthesis to be incorporated in the senior capstone project: Synthesis is defined here as the ability to bring knowledge and skills acquired in various prior coursework to bear on the completion of a comprehensive design and fabrication project and to combine those skill sets in order to achieve an optimum solution. Problem-based learning projects are extremely effective at fostering the ability to perform synthesis (Yadav, Subedi, Lundeberg, & Bunting, 2011).

- The extent to which the product(s) produced by the project may be leveraged in the context of laboratory development: To leverage is to amplify benefit. In the context of laboratory development, then, capstone problem-based learning projects are leveraged when: 1) they result in a new laboratory equipment that adds, enhances, or maintains laboratory capability; 2) the financial value of the equipment produced exceeds the financial investment required to produce the equipment; and, the equipment produced will enhance the learning experiences of subsequent students.

Other factors may also influence the project selection decision. These may include:

- Design constraints: Design constraints include factors such as the available budget, available time for completion of the project, and the size and abilities of the project team.

- The level of entrepreneurial reasoning that the project is intended to engender: Many engineering and engineering technology programs seek to instill an entrepreneurial mindset in their graduates. The Kern Entrepreneurial Engineering Network (KEEN) has identified educational outcomes that exemplify this mindset. These include the ability to integrate information from many sources to arrive at an informed conclusion, the ability to apply systems thinking to complex problems, the ability to evaluate technical feasibility and identify economic drivers, and the ability to assess and manage risk, among others (KEEN, 2018).

A Framework for Project Selection and Leverage Measurement

In this paper, the authors propose a seven-step general, formal decision-making framework.

1. Identify possible laboratory development projects: These projects may involve the design and fabrication of equipment to produce a new laboratory capability, enhance an existing capability, or maintain an existing capability through the replacement of equipment that has reached the end of its useful life.
2. Map each project to student outcomes and program educational objectives: Student outcomes are abilities that each student should possess upon graduation and program educational objectives are statements describing skills and attributes graduates are expected to attain within a period of approximately five years after graduation (ABET, 2018).
3. Identify a project budget: Both the available budget and the estimated required budget on a per project basis must be identified. The work breakdown structure technique is the most commonly employed technique for the generation of estimated project budgets (He, 2014). Remove projects that are likely to exceed the anticipated available budget from consideration: Budgetary constraints may be considered as go/no-go criteria. However, it is often possible to segment these types of projects into a series of phased projects.
4. Assess the scope of each project that has not been eliminated from consideration due to budgetary constraints: In particular, projects that are likely to require a larger team than which is available or that exceed the capabilities of the student team collectively should be eliminated from consideration. Scope considerations may be considered as go/no-go criteria.
5. Perform project selection based upon a formal decision support methodology: The weighted-factor index method is well suited to this task.
6. Implement the project, assess the project's leveraging index, and perform outcome measurements upon project completion: Many outcome assessment techniques are commonly employed and are well discussed in the literature (Duval-Couetil, Shartrand, & Reed, 2016). In this paper, the authors present a method for the calculation of a capstone project leveraging index that may be used for internal benchmarking and for accreditation purposes.

As a decision support tool for project selection, the weighted-factor index method is suggested. The efficacy of this method has been demonstrated in prior research (Hubbard & Jones, 2015). The factors evaluated in the project selection process may be expressed in dissimilar units and have widely varying magnitudes. In addition, many of the factors used for project selection may be subjective rather than objective. The weighted-factor method minimizes the effects of subjectivity and accounts for differing units and orders of magnitude between factors. Each factor is rendered unit-less and normalized to a magnitude between zero and unity through the use of either Equation 1 or Equation 2.

$$\beta_{ij} = \frac{\text{value of factor } i \text{ for candidate } j}{\text{largest candidate factor value under consideration}} \quad (1)$$

$$\beta_{ij} = \frac{\text{smallest candidate factor value under consideration}}{\text{value of factor } i \text{ for candidate } j} \quad (2)$$

where, β_{ij} is the scaled factor i for candidate option j.

Equation 1 is employed when maximizing the value under consideration is considered to be beneficial. For example, a large number of students gaining exposure to the equipment produced by a capstone project is more beneficial than a smaller number of students gaining that exposure. Equation 2 is employed when the minimization of the value under consideration is considered to be beneficial. This is typically the case in which costs are being evaluated. After each factor to be included in the decision-making process has been scaled using either Equation 1 or Equation 2, Equation 3 is employed to generate a weighted-factor index:

$$\gamma_j = \sum_{i=1}^{n} W_i \beta_{ij} \quad (3)$$

where, γ_j is the performance index (also known as the weighted factor index) for alternative j; W_i is the weighting factor for scaled factor i (a measure of the importance associated with the factor); and, n is the number of factors upon which the decision is to be based.

Note that each weighted-factor index (γ_j) will possess a magnitude that lies between zero and unity. Also note that factor weights are typically selected in such a way as to sum to unity. Since this approach uses scaled factor values (β's), the only weighting of factors included in the decision-making process is performed by the weighting factors (W's). Projects exhibiting larger weighted-factor index values are superior to projects exhibiting lower weighted-factor index values.

Capstone Project Composite Leveraging Index

As a method of post-project evaluation, the Capstone Project Composite Leveraging Index (L_{cp}) is proposed. This index is based upon the financial leverage produced by the completion of the project, as well as leverage gained through positive academic impact of the project upon subsequent students. Financial leverage is produced through amplification of funds expended to perform the capstone project. This amplification is realized in the form of the true purchase value of the equipment produced by the project. Academic impact leverage is based upon the number of students who will participate in instructional laboratory learning experiences that employ the equipment produced by the project, as well as the depth and quality of those experiences. The following definitions describe the factors within the L_{cp}.

L_{ssi} = subsequent student impact leveraging index
L_f = financial leveraging index
W_{ssi} = subsequent student impact leverage weighting factor
W_f = financial leverage weighting factor
N_s = the number of subsequent students impacted annually as a result of the capstone project
$N_{s\,max}$ = the maximum number of subsequent students who could potentially be impacted annually as a result of the project
F_{qd} = quality and depth of impact factor
$F_{qd\,max}$ = maximum possible quality and depth of impact factor
C_p = estimated cost to purchase the equipment produced in the capstone project
C_i = cost of actual fiscal investment in the capstone project

Equations 4-6, then, are written as:

$$L_{ssi} = \frac{N_s F_{qd}}{N_{s\,max} F_{qd\,max}} \quad (4)$$

$$L_f = 1 - \frac{C_i}{C_p} \quad (5)$$

$$L_{cp} = W_{ssi} L_{ssi} + W_f L_f \quad (6)$$

The value of the subsequent student leveraging index will always lie within the range from zero to unity, inclusive. The financial leveraging index can attain a maximum value of one. It is possible, though highly unlikely, that the financial leveraging index may possess a value less than zero. A value of the financial leveraging index of less than zero indicates an unsuccessful project. Larger positive values (i.e., values closer to unity) of the subsequent student impact and financial leveraging indices indicate superior leveraging effects. Several considerations are pertinent with regard to the values of the variables employed in Equations 4-6. N_s and N_s max are the number of subsequent students impacted annually as a result of the capstone project, where N_s is an estimate of enrollment in the course(s) that will employ the equipment produced in the capstone project. If, for example, one course is expected to use the equipment for which a leveraging index is being calculated, and if that course is an elective course that has historically exhibited an enrollment of approximately 15 students annually, then the value of N_s may be set at 15 students. The maximum number of students potentially impacted on an annual basis ($N_{s\,max}$) may be set at the enrollment cap of the course or courses in which the equipment is expected to be used.

F_{qd} and $F_{qd\,max}$, representing the quality and depth of impact factor, are to a certain extent subjective. A five-point Likert scale is suggested, using the values one (low quality and depth of impact), two, three (moderate quality and depth of impact), four, and five (high quality and depth of impact). For example, educational laboratory experiences that are deemed to exhibit a high depth of impact, but only a moderate quality, may be assigned a quality and depth of impact factor value (F_{qd}) of four. If the suggested Likert scale is employed, then the maximum possible quality and depth of impact factor (F_{qd} max) value should be assigned a value of five.

C_i and C_p represent the cost of actual fiscal investment in the capstone project (C_i) and should be assigned a numerical monetary value equivalent to the cost of all tools, supplies, and components purchased at the request of the student team in the performance of the capstone project. The estimated cost to purchase the equipment produced in the capstone project should be assigned a numerical monetary value equivalent to the purchase price of a similar piece of equipment with capabilities identical to those of the equipment produced in the performance of the capstone project. It may often be difficult or impossible to obtain quotes from vendors for use in assigning the value of C_p, particularly if the equipment in question is unique or special purpose. An objective method for estimating C_p is discussed in a subsequent section.

W_{ssi} and W_f represent the subsequent student impact leverage weighting factor and financial leverage weighting factor, respectively, and are measures of the relative importance or value placed upon each of the two leveraging effects. These weights are subjective. It is expected that the value or importance associated with the subsequent student impact leveraging index will often be larger than that associated with the financial leveraging index. If the weights assigned to the two indices are approximately equal, it is suggested that a sensitivity analysis be performed to determine whether small changes in weights significantly affect the capstone project leveraging index.

Purchase-Cost Estimation

Much of the equipment produced in the types of capstone projects discussed here is likely to be one-of-a-kind, unique special-order equipment. As a result, it may be difficult to obtain unbiased third-party cost estimates for this equipment, particularly if there is no intent on the part of the inquiring party to actually make a purchase. A general method for the estimation of the purchase cost of these types of equipment is presented here. Custom design/build mechanical fabricators often exhibit experience curve effects (Ghemawat, 1985). As a result, as both design engineers and fabrication personnel become more experienced, the time required to design and build custom equipment grows shorter. In this way, these corporate entities behave in much the same manner as individuals exhibiting learning curve effects. The equations used to predict experience curve effects are similar to those used in the analysis of Wright Learning Curve effects. Note that the devices discussed here are of similar types but are not identical. Equation 7 is used to estimate the time, T_x, required to design and fabricate device *x*:

$$T_x = T_1 x^{\log_2(b)} \tag{7}$$

where, T_1 is the time required to design and fabricate the first device; *x* is the number of devices; and, *b* is the experience curve factor (a measure of the decrease in effort required to produce subsequent devices). Note that $\log_2(b) = \ln(b)/\ln(2)$.

The median salary for mechanical design engineers holding Bachelor of Science degrees in the U.S. is approximately $70,000 annually, which equates to $34.38 per hour, based on 2000 hours per year (PayScale, 2018). On average, approximately 10 years' of experience are required to attain the median salary (PayScale, 2018). If a mechanical design engineer working for a custom design/build enterprise completes four projects per year on average, then that engineer has completed 40 projects, each of which may be of a some-what similar nature at the time that the median salary has been attained. The estimate of four projects annually is conservative. The students completing the senior capstone project may be considered as new, entry-level engineers. As a result, it is reasonable to conclude that the time (in man-hours) expended by the capstone project team may be used as a value for the variable T_1 in Equation 7, and that the value calculated for T_x may be used to estimate the design time required for the "median mechanical design engineer" employed at a custom design/build enterprise if the variable x is assigned a value of 40.

The experience curve factor b typically lies between 0.6 and 0.95 (Ghemawat, 1985). Many enterprises routinely use experience curve factor values between 0.75 and 0.85 in these types of analyses (Ghemawat, 1985). The average value for the experience curve factor from a compilation of numerous studies was found to be 0.85 (Ghemawat, 1985). Companies with large product variety, such as the custom design/build enterprises under discussion, often exhibit experience curve factor values of approximately 0.8 (Ghemawat, 1985). It is recommended for the analysis being described here that the experience curve factor b be set at a value of 0.85. In this way, an estimate of the engineering design time required for a custom design/build enterprise to produce a product similar to that generated in the capstone project being evaluated may be generated. The estimated cost, C_p, to purchase the equipment produced in the capstone project can be calculated using Equation 8:

$$C_p \approx \left[T_x C_{mes}\left(F_{fb}\right) + C_i\right]\left(F_{oh}\right)\left(F_{mu}\right) \tag{8}$$

where, C_{mes} is the median mechanical design engineer salary on an hourly basis; F_{fb} is the fringe benefit factor; F_{oh} is the overhead factor; and, F_{mu} is the mark-up factor.

Note that here, no attempt has been made to account separately for the time required for fabrication. Typical values of F_{fb}, F_{oh}, and F_{mu} are 1.3, 1.2, and 1.5, respectively.

A Case Study of the Use of the Framework for Project Selection and Leverage Measurement

The Mechanical Engineering Technology (MET) Program at Missouri State University routinely employs problem-based learning projects in a number of its courses, including the senior capstone course. The use of linked projects in several courses, leading to the capstone project, has been shown to be an effective method by which to engender entrepreneurial, synthesis-based reasoning in undergraduate students (Buyurgan, Hubbard, & Jones, 2017). An example case of the use of the framework for project selection and leverage measurement is based on a recent delivery of a one-semester course—an engineering design sequence integrated into an engineering technology curriculum. Two potential projects were considered. Both were intended to leverage laboratory capability for use in an advanced computer-integrated manufacturing course, which is also a senior-level course. Project One involved the design and fabrication of a part-transfer device that would receive workparts from a conveyor and deliver those workparts to fixturing in a numerically controlled machining center. Project Two involved the design and fabrication of a device that would replace an automated storage/retrieval system (AS/RS) that had reached the end of its useful life. The project team consisted of three students, each of which was completing his/her final semester.

The two projects to be evaluated in this case study were similar in terms of the program outcomes addressed, the skills desired by employers in graduates of the MET program that they addressed, the level of synthesis that each project would require, and the depth and quantity of entrepreneurial reasoning that they were expected to engender. In particular, it should be noted that the skills and discipline-specific knowledge gained by students in the statics, mechanics of materials, electrical circuits, principles of project management, production planning and control, computer integrated manufacturing, product conceptualization and design, and mechanical design and analysis courses would be required to be synthesized in order to successfully complete either Project One or Project Two. Both projects pass the go/no-go criteria with regard to available budget and project scope relative to the size and capabilities of the project team.

The factors in which the two projects vary are their potential leveraging impact, their level of complexity, and their anticipated cost. Note that project complexity is defined here as the level of fit of the project scope with the size and capabilities of the project team. Potential leveraging impact, at this phase of project evaluation, must be evaluated using the Delphi method, and may be enumerated using a five-point Likert scale ranging from one (low potential impact) to five (high potential impact). Project complexity as a measure of level of fit is also enumerated using a five-point Likert scale ranging from one (project too complex for the size and abilities of the project team) to five (project provides an exceptionally good fit with regard to the size and abilities of the project team). The anticipated cost of each project was estimated based on the past experience of the faculty in completing similar projects, both in an academic setting and in funded research activities. Table 1 details the factors that might be used to evaluate these projects and the weights assigned to each factor.

Table 1. Project selection factors.

Factor	Weight (%)	Project One	Project Two
Potential Leveraging Impact	50	3	4
Level of Complexity	20	5	4
Anticipated Required Budget	30	\$2,500	\$1,500

The potential leveraging impact and level of complexity factors are superior when the numerical value of each factor is larger. As a result, Equation 1 is employed in the calculation of the scaled values for these factors. Equation 2 is employed in the calculation of the scaled value for the anticipated required budget factor, since for this factor small values are superior. The variables β_{pli}, β_{lc}, and β_{arb} are defined as the scaled factors for potential leveraging impact, level of complexity, and anticipated required budget, respectively. Table 2 details the scaled factor values for each project.

Table 2. Scaled factor values and weighted factor index by project.

Project	β_{pli}	β_{lc}	β_{arb}	γ_j
One	0.75	1	0.6	0.76
Two	1	0.8	1	0.96

The β_{pli} calculation for Project One is presented as an example. A larger value of potential leveraging impact is desirable and, as a result, Equation 1 is employed. The largest potential leveraging impact for either project is four and the potential leveraging impact for Project One is three. Then, for Project One:

$$\beta_{pli} = \frac{3}{4} = 0.75$$

The weighted factor index for Project One is calculated as:

$$\gamma_1 = 0.5(0.75) + 0.2(1) + 0.3(0.6) = 0.76$$

Project Two exhibited a weighted factor index value of 0.96, which is superior to that exhibited by Project One. As a result, it is reasonable to select Project Two for completion as a senior capstone project. Project Two was completed by three students in the final semester of their programs of study. A budget of \$1500 was made available for the team's use. The goal of the project was to design and fabricated a suitable replacement for an AS/RS located in the MET Program's Computer Integrated Manufacturing Laboratory. The replacement device was to be produced at a considerably reduced cost compared to the purchase price of a new AS/RS and the replacement device was required to exhibit a higher reliability than that of the original equipment. In addition, the replacement device was required to be capable of handling multiple workpart types and was to be capable of being controlled using a programmable logic controller. The original AS/RS had stored pallets sized to fit an existing conveying system. Figure 1 shows the original AS/RS.

Figure 1. Original AS/RS.

The project team developed a product function statement and generated engineering specifications from that product function statement. Based on those specifications, the project team determined that the functionality embodied in the original AS/RS could be achieved using a system based on flexible modular fixturing. This fixturing consists of two parts: a pallet and a traveler. Using this concept, pallets are not removed from the conveying system. Rather, pallets travel on the conveying system continuously. The raw material to be fed to the conveying system is stored in a traveler, which is a relatively small fixture base with an array of tapped holes that can receive modular fixturing elements suitable for a wide variety of workparts. Figure 2 depicts a pallet. Figure 3 depicts a traveler. Based on this concept, the project team generated five design concepts, evaluated those concepts, and selected one concept to proceed to the detailed design phase of the project. Figure 4 depicts an assembly drawing of the traveler feeder that was designed, fabricated, and integrated in the flexible manufacturing system by the project team. The project team met or exceeded each of the project objectives.

Figure 2. Pallet.

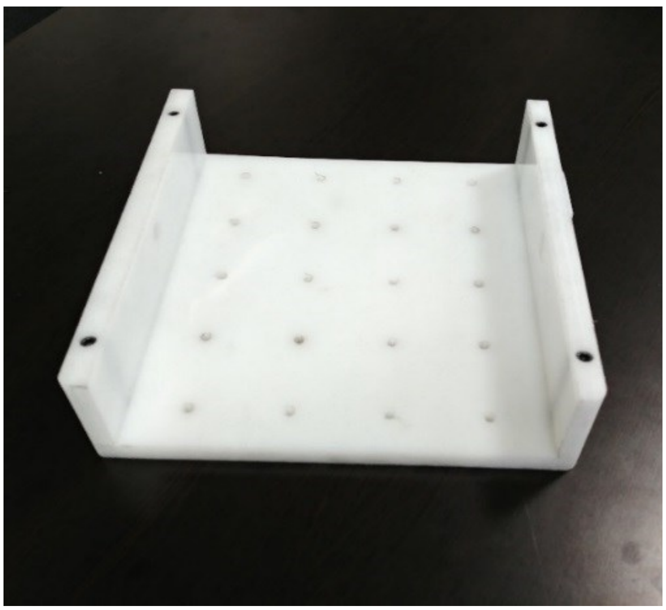

Figure 3. Traveler.

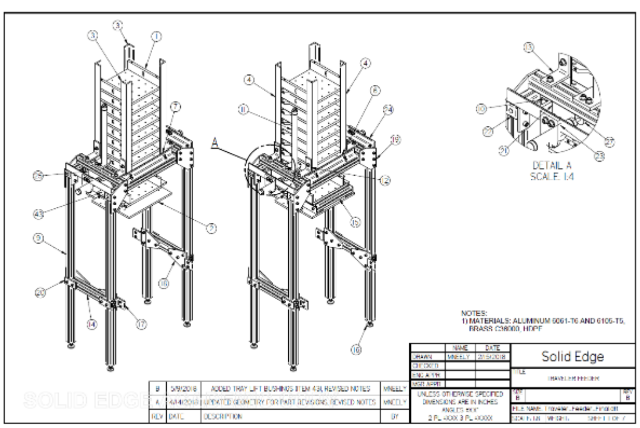

Figure 4. Assembly drawing of traveler feeder.

The project team tracked a total of approximately 600 man/hours spent in performing the project, and expended $1275 for the purchase of tools, supplies, raw material, and components. Employing the 600 man/hour value in Equation 7, with the variable *x* set at 40 projects and the experience curve factor, *b*, assigned a value of 0.85:

$$T_x = 600\left(40^{\log_2(0.85)}\right) = 253 \text{ man} \bullet \text{hr}$$

Using the values of 253 man/hour time expenditure, $34.38 per hour median mechanical engineering design salary, and $1250 cost of supplies, materials, and tooling in Equation 8, and employing typical F_{fb}, F_{oh}, and F_{mu} values of 1.3, 1.2, and 1.5, respectively, C_p was estimated as:

$$C_p \approx \left[253 \text{ man} \bullet \text{hr}\left(\frac{\$34.38}{1 \text{ man} \bullet \text{hr}}\right)(1.3) + \$1{,}250\right](1.2)(1.5) = \$22{,}600$$

The quality of the educational experience in which students will engage using the equipment produced in this project was evaluated at a "high" rating. The depth of this experience is only moderate, since the duration of the anticipated laboratory experience that will employ this device is relatively short. As a result, the quality and depth of impact factor (F_{qd}) was assigned a value of four. Using the same five-point Likert scale, the maximum possible value for the quality and depth of impact factor ($F_{qd\,max}$) was five. Setting a value of 15 students per year for historical average enrollment in the advanced computer integrated manufacturing course in which the equipment is intended for use, and setting the enrollment cap for this course at 25 students per year in Equation 4 yields:

$$L_{ssi} = \left[\frac{15 \text{ students/yr } (4)}{25 \text{ students/yr } (5)}\right] = 0.48$$

Employing the $1250 value for C_i and the $22,600 value for C_p in Equation 5 yields:

$$L_f = 1 - \left[\frac{\$1{,}250}{\$22{,}600}\right] = 0.94$$

Employing the values for subsequent student impact leveraging index and financial leveraging index in Equation 6, and assigning weights of 70% and 30% to each of these two indices respectively yields:

$$L_{cp} = 0.7(0.48) + 0.3(0.94) = 0.62$$

The financial leveraging index (L_f) for this capstone project was near to unity, indicating very good financial benefit amplification. The subsequent student impact index (L_{ssi}) was slightly less than 0.5, indicating a moderate academic benefit resulting from the laboratory capability maintained through the implementation of this capstone project. The composite capstone project leveraging index (L_{cp}) was slightly more than 0.5, which indicates a high-moderate total leverage. This analysis indicates that an excellent financial benefit and a significant academic benefit were derived from this capstone project. This also provides a baseline for the evaluation of the success of future capstone projects.

Conclusions

In this paper, the authors presented a formal, general seven-step procedure for the selection of senior capstone projects in engineering and engineering technology programs, as well as a method by which to evaluate the leveraging effects of those projects. Using these methods, projects may be selected in order to achieve maximum financial and academic impact, and the measurement of those impacts may be used both for internal benchmarking and for accreditation continuous improvement tracking purposes. In addition, a case study employing these methods based upon a recent delivery of a senior capstone course in the MET program at Missouri State University was presented. Some subjectivity was present in the weight-assignment phases of the analysis. As a result, it is recommended that at least an informal sensitivity analysis be conducted in order to determine the extent to which changes in weight assignment affect the final conclusion of the analysis, if the values assigned to the weighting factors are nearly equal. Future investigation should be conducted after the procedure and methodology described in this paper has been employed over time in order to determine whether these tools facilitate continuous improvement in project leveraging. The baseline established in the project described in the case study portion of this paper will be employed for this purpose.

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Role of Measurement System Analysis in Capstone Production

Mustafa Shraim, Ohio University; William Neil Littell, Ohio University; Zaki Kuruppalil, Ohio University

Abstract

In this study, the authors integrated all of the requirements of the production part approval process (PPAP) into a senior capstone course in the College of Engineering at Ohio University. PPAP is a method that component suppliers of automotive manufacturers use to properly carry out and document all customer requirements. The PPAP methodology was developed by the Automotive Industry Action Group (AIAG) and primarily used in the supply chain to establish confidence in component suppliers and their production processes. It includes conducting several studies and analyses, such as failure mode and effects analysis (FMEA), advanced product quality planning (APQP), and measurement systems analysis (MSA), among others. In this paper, the authors focus on the MSA component and the validation of measurements using gage repeatability and reproducibility (GR&R) methods. The aim of this study was to introduce GR&R into the senior capstone process by answering two questions: 1) are students aware of how significant measurement system variation can be when compared to total variation; and, 2) what can be done if the GR&R study results do not satisfy standard requirements? An example with capstone production data will be presented.

Introduction

The increase in outsourcing of components and subassemblies to external suppliers, including those offshore, created the need for standardizing the approval process. The production part approval process (PPAP) is considered a valuable and rigorous program for establishing confidence in the manufacturing process of component and subassembly suppliers (AIAG Work Group, 2006). PPAP initially started in the automotive industry but was adopted by other industries over time. It is becoming a common language for communicating expectations to suppliers regarding the qualification of the manufacturing process. Therefore, it is imperative that engineers entering the workforce have a hands-on understanding of PPAP and the interactions among its parts.

The PPAP manual, along with other relevant documents, is published by the Automotive Industry Action Group (AIAG). This non-profit organization was initially founded in 1982 by representatives of the “Big 3” automotive manufacturers in North America: Ford, General Motors, and Chrysler. Since then, other manufacturers, both in the automotive as well as other industries, have become members of the organization. This includes, among others, original equipment manufacturers and their Tier 1 suppliers. In the automotive industry, the quality management system requirements are governed by the International Automotive Task Force through its standard, IAFF 16949 (2016). This standard includes all requirements in ISO 9001 (2015) as its core in addition to other requirements, such as production part approval. Generally, there are five submission levels under PPAP. These levels determine what is involved, the documentation required, as well as sample submission requirements. Table 1 shows the levels, as published in the PPAP manual by AIAG.

Table 1. PPAP submission levels.

Level	Description of Requirements
1	Submission Warrant and designated Appearance Approval Report
2	Submission Warrant, with product samples and some supporting data required by the customer
3	Submission Warrant, product samples, and complete supporting documents
4	Submission Warrant and other requirements as defined by the customer
5	Submission Warrant, product samples, and complete supporting documents at the supplier’s manufacturing site.

Typically, level 1 is applicable when minor changes of an already approved PPAP submission occur. For example, physically moving the manufacturing process within a facility may trigger a level 1 submission. On the other hand, level 5 is for initial submissions of parts that involve safety features, while level 3 is the default submission for most situations. Depending on the level, each submission consists of up to 18 items that must be either submitted and/or retained at the manufacturing location for review by the customer upon request. Examples of items submitted are Design FMEA, Design Flow Diagram, Process FMEA, Control Plan, and Measurement System Analysis (MSA). In this paper, the authors focus on MSA with Gage Repeatability and Reproducibility (GRR) studies as its analysis output (AIAG Work Group, 2010).

Measurement Systems

A measurement system is the process used to acquire data for a quality characteristic of a given product so that a decision can be made on its status. Ideally, no errors come from the measurement system. In practice, however, this objective is impossible, given the variation in the measuring equipment as well as between and within operators performing the measurement (appraisers). When an error exists in the measurement system, the true value of the characteristic being measured could be either overestimated or underestimated. If this deviation is substantial relevant to the tolerance, this may lead to one of the two types of errors or mistakes that may be committed (Deming, 1982; Montgomery, 1991).

1. Type I Error: This type occurs when good a product that genuinely conforms to established specifications is deemed unacceptable. This is also referred to as a "false alarm" or "producer's risk." This is equivalent to treating variation coming from common-cause, as if it is a particular cause.
2. Type II Error: This type results when the nonconforming product is deemed acceptable and moved on to the next stage (e.g., customer). This is often referred to as consumer risk. This is equivalent to not reacting to special-cause variation.
3. The difference between the true value and the measured value can be due to accuracy, precision, or both. The accuracy is the deviation of an average of repeated measurements from the true value, while precision refers to the scatter of measurement around the true value (Juran & Gryna, 1980). A rule of thumb is that the precision of the measuring equipment should be such that its total variability is one-tenth of the tolerance being measured (Feigenbaum, 1991). For example, for a part of tolerance of 0.0300 inches, the variability from the measuring equipment should not exceed 0.0030. This equipment should be capable of reading 0.003-inch calibration marks.

The two types of errors mentioned above may be committed when the measurement system is inadequate. That is, the variation attributed to its components is too large when compared to total variation. Figure 1 shows the breakdown of sources of variation. As shown in Figure 1, total variation (TV) in a measured characteristic is comprised of the actual or part-to-part variation (PV) as well as the measurement system variation (MS) (Barrentine, 1991). If the measurement system includes appraisers in addition to the measuring equipment, then MS must account for both. Mathematically, Figure 1 can be represented by Equation 1 for the total variation (TV) and Equation 2 for the measurement system (MS), respectively.

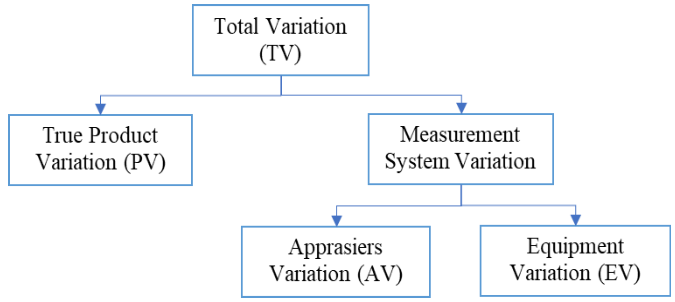

Figure 1. Breakdown of variation components.

$$\sigma^2_{Total} = \sigma^2_{PV} + \sigma^2_{MS} \tag{1}$$

$$\sigma^2_{MS} = \sigma^2_{Appraisers} + \sigma^2_{Equipment} \tag{2}$$

The objective of MSA is to quantify measurement errors by assessing the two sources of variation (appraisers and measuring equipment). Variability attributed to the appraisers is commonly referred to as reproducibility, and the one attributed to the measuring equipment is referred to as repeatability (AIAG-Work Group, 2010). Thus, variation (standard deviation) for gage repeatability and reproducibility (GR&R) is expressed mathematically in Equation 3:

$$\sigma_{GRR} = \sqrt{\sigma^2_{Appraisers} + \sigma^2_{Equipment}} \tag{3}$$

In analyzing measurement systems, it is often desirable to break down the GR&R variation into its components. By separating these sources of variation in the measurement system, effective countermeasures can be applied. For example, if GR&R variation is mostly due to the measuring equipment, it may be more useful to repair, calibrate, or use a replacement. On the other hand, if appraisers show they are not consistent (or their results are not reproducible), it may be time to invest in standardizing methods of measurement as well as training of appraisers. There are different methods used in analyzing measurement system or gage studies (Wheeler, 2013). Individually, these methods are:

- Analysis of variance (ANOVA) (Burdick, Borror, & Montgomery, 2003)
- AIAG (X-bar and R) (AIAG, 2006)
- Evaluating the measurement process (EMP) method (Wheeler & Lyday, 1989)

There are differences between these methods in the way they estimate the component standard deviations before the overall GR&R variation and contribution are calculated. These analyses are included in many of the commonly available statistical analysis software offered in the market. In this current analysis, both AIAG and ANOVA were used for analysis and comparison. In the automotive industry, it is a standard practice to require the GR&R variation to be within 10% of total variation. If the GR&R variation is greater than 30% of total variation, then the measurement system is considered unacceptable. For situations in which the GR&R is between 10% and 30%, the results could be acceptable, or conditionally acceptable, depending on the application, among other factors (AIAG, 2006). When the measurement system is deemed unacceptable, it is customary that corrective action is applied and the GR&R study is run again.

As mentioned previously, the authors aim to introduce GR&R into the senior capstone process by answering two questions: 1) are students aware of how significant measurement system variation can be when compared to total variation, and 2) what can be done if the GR&R results do not satisfy standard requirements? For the first question, a survey was conducted for the overall PPAP perception with multiple open-ended questions. Among the questions or requested information, students were asked to describe the role of variation in both the part and the process. For the second question, GR&R studies were conducted and analyzed.

Results and Discussion

Among the questions or requested information in the survey, students were asked to describe the role of variation in both the part and the process. Out of the 25 students in the class, almost all the responses addressed variation in the manufacture of the parts and not necessarily the measurement system. Here are some examples of their responses.

- "Variation in the process creates variation in the parts produced"
- "Variation in the part is the difference between parts that are theoretically supposed to be the same. This type of variation is extremely common and does not necessarily create quality issues. Variation in the process is variation in how the part is made, and this is a much more destructive type of variation. This commonly causes quality issues and creates many problems in manufacturing"
- "No matter how precise a part or process is there will always be variation. it is impossible to produce parts consistently that are perfectly the same. with that variation in parts is how parts differ from one another. variation in process is the difference in the same process by different suppliers that yield different results"
- "It is desirable to have as little variation as possible. This is because it will help reduce product defects and ensure that there is a consistency with the parts being produced"
- "Variation in the part is due to variation in the process. If the company making the part has a process that is not tightly controlled, there will be variation in the part"

A couple of responses indirectly addressed the issue of the measurement systems.

- "It is important to get your process under control then you can start improving it"
- "Processes have variation such as operator methods and external factors that need to be controlled"

These results clearly show that students do not think of measurement system variation when they are asked about part and process variation. Instead, they only think of variation in making the product. However, and as shown in Figure 1, overall part variation (perception) is made up of two components: part-to-part (true) variation and measurement system error. To answer the second question, three teams in the senior capstone class participated in this GR&R study with three appraisers from each team. These are the same teams that would eventually complete the PPAP process in the second capstone class. Before the start of the study, an overview of measurement system analysis was conducted in order to explain how measurement system variation is related to overall variation. Upon the completion of the overview, three volunteers from each team completed the GR&R studies in two phases.

- Phase I: Conduct the GR&R study per instructions given.
- Phase II: Conduct the GR&R study by making simple improvements to minimize variation explained in the overview. The measuring method may vary from team to team.

A set of 10 parts similar to components that will potentially be in a capstone project were used to measure a designated dimension by three appraisers from each team using a provided pair of calipers. It should be mentioned here that each team used the same pair of calipers in both phases. In addition to the three appraisers, the study was coordinated by faculty members to ensure integrity of results. Table 2 outlines the process for completing the measuring and recording process. In this study, three trials were used. For each phase, 90 measurements per team were taken (10 parts x 3 appraisers x 3 trials). A statistical software package was used to analyze the data using the AIAG method for both phases (before and after improving or standardizing the measurement process by each team). It should be mentioned that six standard deviations were used as the overall process spread covering 99.73% of the area under the normal distribution. The default for the AIAG is to use 99% of the area which spreads over 5.15 standard deviations. Additionally, The ANOVA method was run once, along with the AIAG method, for comparison purposes. Tables 3-5 display the results for the three teams in Phase I.

Table 2. Gage study instructions.

Step	Instruction
1	Appraiser 1 measures all 10 samples in a random order
2	After each measurement read by an appraiser, it is verified and recorded by the coordinator
3	Steps 1 and 2 are repeated for the other appraisers
4	For each additional trial, have each of the appraisers repeat steps 1 and 2

The commonly reported results for GR&R studies are under the "% Study Variation" column. This indicates the extent of GR&R variation when compared to the overall variation. The average GR&R variation for the three teams for Phase I was about 63%. In other words, 63% of the total variation was due to the measurement system, which is not acceptable according to the AIAG standards (2006). Furthermore, on average, there was more variation in the measuring equipment (repeatability) when compared to appraisers (reproducibility), of approximately 54% to 33%. This is an indication that the measuring equipment needs attention, such as maintenance, calibration, or possible replacement. This was not within the scope of the study. The percentages in GR&R and part-to-part components do not add to 100%, since the standard deviations cannot be added but rather the variances, as shown in the previous section.

The "% Tolerance column" in Tables 3-5 refers to the percentage of component variation as compared to specifications. For example, the GR&R component in Table 5

Table 3. Team 1 results before standardization.

Appraisers: Team 1			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.0028227	0.0169362	59.89	56.45
Repeatability	0.0023436	0.0140615	49.72	46.87
Reproducibility	0.0015733	0.0094398	33.38	31.47
Part-to-Part	0.0037747	0.0226483	80.08	75.49
Total Variation	0.0047134	0.0282803	100.00	94.27

Table 4. Team 2 results before standardization.

Appraisers: Team 2			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.0027283	0.0163697	63.69	54.57
Repeatability	0.0023633	0.0141796	55.17	47.27
Reproducibility	0.0013633	0.0081795	31.82	27.27
Part-to-Part	0.0033029	0.0198172	77.10	66.06
Total Variation	0.0042840	0.0257039	100.00	85.68

Table 5. Team 3 results before standardization.

Appraisers: Team 3			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.0024537	0.0147219	65.49	49.07
Repeatability	0.0021171	0.0127026	56.51	42.34
Reproducibility	0.0012403	0.0074417	33.11	24.81
Part-to-Part	0.0028310	0.0169862	75.57	56.62
Total Variation	0.0037464	0.0224781	100.00	74.93

shows 49.07% contribution of the "6 x Std Dev" value of 0.0147 inches, when compared against the tolerance of 0.0300 inches. This information could be relevant; if the overall process capability is high, that measurement error may be deemed insignificant. For Phase II, the teams were asked to come up with ways to standardize the method of measuring the parts. Without further involvement from faculty, each team devised simple steps to standardize how they could measure the parts to improve consistency between appraisers. Below are some examples of standardization the teams used.

- Orienting part with respect to a marking on the part.
- Ensuring perpendicularity between part and calipers; standing the part on end on the table, placing the calipers on the table and using the center of the calipers.
- Placing the sample completely in the calipers to maximize contact area across the surface of the device

The teams repeated the GR&R study for Phase II and data were analyzed in a similar. Results are displayed in Tables 6-8. The results in Tables 6-8 show that, on average, GR&R variation was reduced from 63% in Phase I to 41.5% in Phase II, or about one-third. Although this is still not acceptable according to the AIAG standards, it is a significant improvement made only by introducing simple steps to standardize the process. Figure 2 compares GR&R results between the two phases for the three teams. As mentioned in Phase I, the "% Tolerance column" in Tables 3-8 shows the percentage of component variation as compared to specifications. Table 8 shows a GR&R component with 49.35% contribution ("6 x Std Dev" value of 0.0148 inches when compared against the tolerance of 0.0300 inches).

The ANOVA method for analyzing the GR&R data was also run for one case to compare against the AIAG (or X-bar and R) method. The results are shown in Tables 9-11.

Table 6. Team 1 results after standardization.

Appraisers: Team 1			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.002687	0.016123	49.21	53.74
Repeatability	0.001142	0.006854	20.92	22.84
Reproducibility	0.002432	0.014594	44.55	48.65
Part-to-Part	0.004753	0.028520	87.05	95.07
Total Variation	0.005460	0.032762	100.00	109.21

Table 7. Team 2 results after standardization.

Appraisers: Team 2			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.0011903	0.007142	21.07	23.81
Repeatability	0.0009256	0.0055537	16.39	18.51
Reproducibility	0.0007484	0.0044905	13.25	14.97
Part-to-Part	0.0055223	0.0331336	97.75	110.45
Total Variation	0.0056491	0.0338946	100.00	112.98

Table 8. Team 3 results after standardization.

Appraisers: Team 3			Specifications: 0.3850 ±0.0150	
Source	Std Dev.	6 x Std. Dev.	% Study Var	% Tolerance
Total GR&R	0.002468	0.014806	54.19	49.35
Repeatability	0.002058	0.012348	45.19	41.16
Reproducibility	0.001362	0.008169	29.90	27.23
Part-to-Part	0.003827	0.022963	84.04	76.54
Total Variation	0.004554	0.027322	100.00	91.07

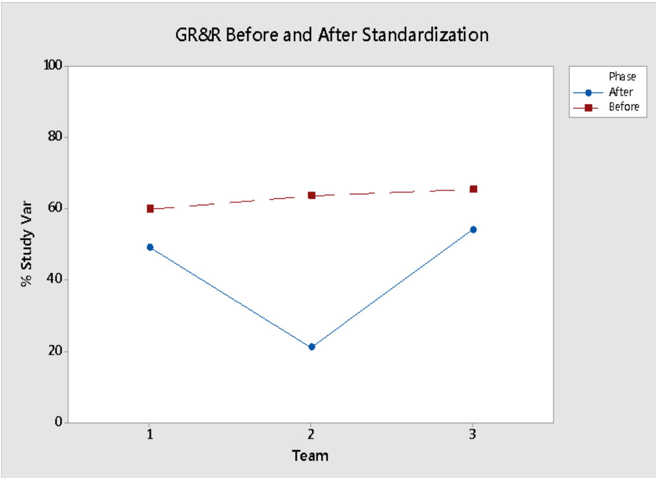

Figure 2. GR&R results.

Table 9. Two-way ANOVA with interaction (Team 2, Phase II).

Source	DF	SS	MS	F	P
Parts	9	0.0027358	0.000304	203.655	0.000
Appraisers	2	0.0000387	0.0000193	12.960	0.000
Parts * Appraisers	18	0.0000269	0.0000015	1.311	0.214
Repeatability	60	0.0000683	0.0000011		
Total	89	0.0028697			

Table 10. Two-way ANOVA without interaction (Team 2, Phase II).

Source	DF	SS	MS	F	P
Parts	9	0.0027358	0.000304	203.655	0.000
Appraisers	2	0.0000387	0.0000193	12.960	0.000
Repeatability	78	0.0000952	0.0000012		
Total	89	0.0028697			

Table 11. GR&R results using AIAG vs. ANOVA.

Source	AIAG % Study Var	ANOVA % Study Var
Total GR&R	21.07	22.68
Repeatability	16.39	18.55
Reproducibility	13.25	13.05
Part-to-Part	97.75	97.39
Total Variation	100.00	100.00

Table 9 shows that the interaction between Parts and Appraisers is not significant. This means that the variation there is considered random. As a result, this component can be combined with the "Repeatability" component, as shown in Table 10. In Figure 3, the chart on the bottom right shows close to parallel lines for operators across parts, indicating no significant effect for the interactions between parts and appraisers.

Figure 3. Example of GR&R results (Team 2, Phase II).

The GR&R and component contributions based on the ANOVA method were calculated and compared to the AIAG method in Table 11 (ISO, 2015; AIAG Work Group, 2010). These results show a slight difference between the two methods. However, the ANOVA method determines if there is an interaction effect between parts and appraisers. If the interaction is significant, then this should be investigated and corrected before running the study again.

Conclusions

As PPAP methods are being introduced to the senior capstone classes, students need to understand the importance of the measurement system process and analysis. In this paper, the authors demonstrated through a survey that students were not aware of the relationship between measurement system variation and total variation. In addition, measurement system studies were conducted to show, for example, that measurement variation can inflate the total variation, which could result in making erroneous decisions. These decisions can have an impact on the bottom line through increasing failure costs of quality. They can also have a detrimental effect on customer satisfaction, as nonconforming products may be received by the customer due to committing type II errors.

With an average GR&R variation of 63% of total variation, the measurement system analysis in Phase I showed how large the measurement system error could be when compared to total variation. In Phase II, applying simple steps to standardize the measurement process among appraisers, the GR&R percent contribution was reduced by one-third. These results will be shared with the teams involved at the beginning of their second capstone class. As shown in the results of Phase II (Tables 6-8), Team 2 appeared to reduce GR&R variation by two thirds—from 63.69% to 21.07%. It would be worthwhile to see if the other two teams could realize similar results, should they follow the measurement process employed by Team 2. Furthermore, the measuring equipment variation could be reduced by investigating the device for calibration status or using an alternate. Finally, another study could be conducted using a high-precision, no-contact measuring system to estimate overall variation and then compare those result to results obtained in this study.

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Proposal for a CHATBOT to Conduct Human-Like Conversation with Students of Eastern Illinois University

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Abstract

Eastern Illinois University has a great social media presence on Facebook, Twitter, etc., along with the university's own website. People prefer to contact university officials using chat platforms instead of phone or email. It is difficult to manage so many pages and sites 24 hours a day without a large labor force. In this study, the authors analyzed how EIU can provide services to students without manpower through such chat platforms. The automation of chat conversations is a good solution for meeting this requirement. This study resulted in the creation of a chatbot that can chat with students 24 hours a day. Chatbots are applications that can send and receive messages and, in many cases, act as a human counterpart to provide services to users. The chatbot is based on natural language processing methodology. The chatbot can attach to social networking websites and university websites. Chatbot can answer student questions intelligently because of a machine-learning model and data training. DialogFlow framework helps to develop this chatbot. Multiple intent and context elements are created in chatbot development to respond to student questions. If the chatbot training uses enough examples, then users can expect good performance. The chatbot can integrate with multiple instances.

Introduction

A chatbot is an automated program that provides highly engaging, conversational experiences (Abdul-Kader & Woods, 2015). A chatbot responds to both voice and text messages. Such chatbots can be implemented on websites and mobile applications as well as social media platforms such as Facebook Messenger, Slack, Twitter, etc. (McTear, 2018). Many organizations that cannot operate user support services 24 hours a day will find chatbots to be very useful in dealing with customer queries. Chatbots have increased in their complexities as well as their usefulness over the last few years to help users. Many chatbots work on a predetermined script. This kind of chatbot works fine in most cases, but sometimes it would be very difficult to handle all of the user questions if the questions are not in the script. Incorporating natural language processing (NLP) in the chatbot makes it capable of handling user questions in an intelligent manner (Liddy, 2001). Figure 1 shows different types of chatbot creation technologies. In the first generation, a chatbot is defined using predefined rules. If a customer says something, then chatbot should respond with a specific answer. Supervised machine learning is used in the second generation with the help of labeled data. In this model, the system (chatbot) can understand the user input intent and respond with labeled answers, but the system needs more labeled data for training. In the third generation, the system can be trained using unlabeled data with the help of adaptive and unsupervised machine learning. However, adding first- and second-generation technologies will also help improve the system to respond to user questions in a variety of contexts.

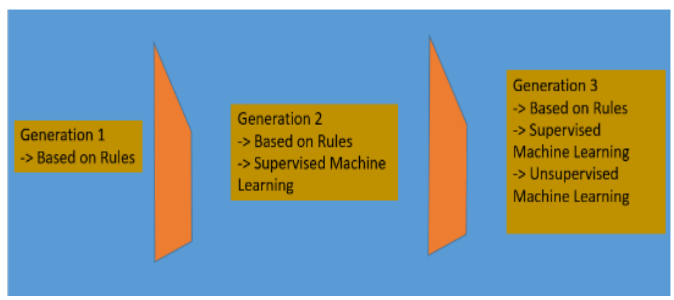

Figure 1. Types of chatbot technology.

Machine learning is classified into two types: supervised machine learning and unsupervised machine learning. Supervised machine learning expects input from variable X from the user, and it will map to the appropriate output variable Y. In unsupervised machine learning, the system expects input from the user and will not map to any particular output variable, but it can be capable of answering by observing the data. Supervised machine learning methodology -based platforms are used in developing a chatbot to have conversations with users. The natural language process is very powerful in understanding user input (Abdul-Kader & Woods, 2015), because this helps the chatbot to understand the intent of the user input. Understanding the intent is helpful in having a rich conversational experience with users, but building an NLP engine requires a good amount of machine learning skills and more data (Liddy, 2001).

Specific Problem

In this study, the authors had to deal with the problem of responding to student queries (and/or prospective students) at Eastern Illinois University, which offers admissions to both domestic and international students. The domestic and international admissions team provides answers to student questions through messenger or email between 8:00am and 4:00pm Monday through Friday. In the case of domestic student admissions, university officials mostly receive questions during this time period, but sometimes questions related to international admissions can be after 4:00pm, due to time-zone differences. This time difference causes delays in answering student questions. Furthermore, many students (or prospective students) at the university have questions in diverse areas—such as finance, housing, scholarships, program-specific questions, etc.—that can only be resolved by university officials. Each department in the university, such as admissions, graduate office, etc., has a specific knowledge-based team. A student expects immediate solutions for queries from university officials; sometimes, however, due to a large number of questions, it becomes difficult to respond promptly.

Many students would like to contact university officials on weekends, but university offices are not open then. Hence, the response is automatically delayed. Every student expects a fast and accurate response from the university, but maintaining office hours 24/7 is not practical for EIU. This affects students from outside the U.S. the most, as they face delayed responses due to differing time zones. Additionally, it is well known that humans can make mistakes, due to lack of skills and knowledge. But having a knowledgeable and skilled employee available to answer student questions, without making any errors, around the clock would be virtually impossible.

Research

The university requires a system that can provide quick and accurate responses to students' specific questions from university officials. Managing social media platforms on a continuous basis is very difficult for the university. Developing an application that can handle student questions automatically by understanding the intent of the question is the best way to resolve the problem. A chatbot can be developed using traditional programming languages including a certain set of rules. However, it is not practical to predict all possible questions and create that many rules in chatbot application development. It is important to understand the student's intent in the question in order for the chatbot to provide an accurate answer. Natural language processing is the best way to understand the intent of the question.

Figure 2 explains how NLP helps the machine to understand the human language and perform a set of actions, such as text summarization, sentiment analysis, speech recognition, etc. NLP algorithms typically are based on machine-learning algorithms. Natural language processing is involved in natural language understanding (Liddy, 2001). It is clear from Figure 2 that a machine can interact with more human languages by using NLP.

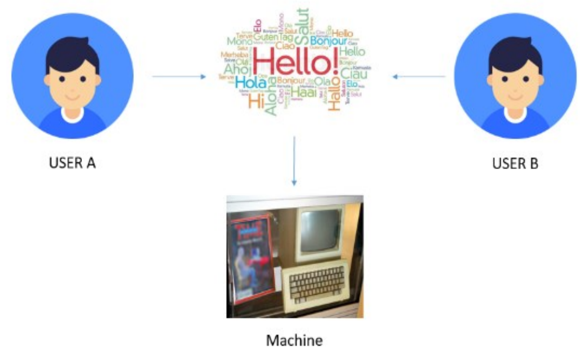

Figure 2. Natural language understanding.

Natural Language Understanding

The idea of exploring how the machine can understand human instruction started in 1971, when Terry Winograd developed the SHRDLU robot that was able to convert human commands into machine commands, such as "move the red pyramid next to the blue pyramid," (see Figure 3). To act in this way, the system needs to build up semantic knowledge (Winograd, 1971).

Example:

Person:	*Pick up a blue block.*
System:	*OK.*
Person:	*Hit the pyramid.*
Computer:	*I am not understanding which pyramid you are talking about.*

Figure 3. Blocks of various shapes and sizes.

Linguistic Analysis

Three major parts of linguistic analysis are syntax, semantics, and pragmatics. Syntax deals with the grammar of the sentence. In a simple way, successful syntax means a lack of grammatical mistakes. Semantics explains the meaning of the words and sentence; correct grammar is not the only criterion for a meaningful sentence. Pragmatic is the main goal or purpose of the sentence that points to the main theme or larger context of the conversation (Liddy, 2001). Tokenization is part of syntax analysis or signal processing between signal processing and syntax analysis, converting the input signal into several parts for easy computation. Figure 4 shows how the NLP layer acts as a medium to perform natural conversation with users. The NLP layer receives messages from users and can answer by using data from the database system (Liddy, 2001).

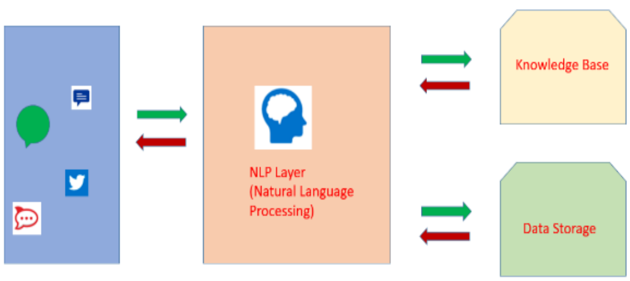

Figure 4. Working of NLP layer.

The chatbot development used by the DialogFlow framework platform was used to build a bot to resolve the problems noted above. DialogFlow is a powerful tool for building chatbots for natural conversation with students (Bot, n.d.). This platform is based on NLP methodology and is enhanced with the help of machine learning. All the NLP-related considerations require care by the DialogFlow tool to develop a chatbot, and the developer must train the bot with certain data to perform intelligent operations. The following items are necessary for chatbot creation.

Invocation will allow a chatbot to start a conversation with students. Developers can define their own invocation to initiate a conversation and select recognizable terms as invocations to define in a chatbot (Debasatwa, 2017).

Example:
"Hi Panther, I need admission details..."
"Hi Panther, I need university address…"s
"Hi Panther, I need help…"

An intent is a defined action in DialogFlow that can be triggered by a user (Debasatwa, 2017). The NLP methodology can understand the user's question and predict the correct intent based on that question. There are actions needed for defining the intent of handling a user's question. Developers can create a default intent for each chatbot, which will trigger if no user question is mapped to a particular intent in the chatbot. Intent has four sections for receiving a trigger intent and responding to the user:

- Training phrases
- Action
- Response
- Contexts

In each intent, a training phrase option is available that triggers the intent and provides an accurate answer to a given question. It is very difficult to know how a user may frame a question. Users can expect intelligent responses from the chatbot based on different kinds of questions defined in the training phrase option, including context elements that can help the chatbot identify the context of the question.

Action has name and parameter fields to perform a specific action based on parameter values (Debasatwa, 2017). A user sometimes does not provide the required values in the question to provide accurate responses, in which case the action and parameter values may help to extract the required details from the users.

An agent response can add in a response area as well as multiple responses in one intent to add variation to the answer. There is an option to add parameter reference values in agent response (Debasatwa, 2017).

Context helps to pass on information from previous conversations or external sources (Debasatwa, 2017). If a chatbot behaves in an intelligent manner, then it should know the context of the conversation.

Discussion

The chatbot developed using DialogFlow is based on labeled data training. It can understand the intent of the question and trigger suitable intent in the list of available intents in the agent. This framework is based on supervised machine learning. The chatbot cannot train itself using the unlabeled text data and user conversion data. This kind of chatbot has difficulty handling different kinds of questions. An unsupervised machine learning-based chatbot will perform better and carry out more intelligent conversation than a supervised machine learning-based chatbot. Sometimes it is difficult for a chatbot to answer all of the questions posted by the user, due to lack of suitable data training. It is difficult to expect high performance from a chatbot initially, because developers must observe the chatbot's performance and its responses to user questions. If the chatbot fails to provide answers to any specific set of questions, then developers need to re-train it to make it more intelligent. Continuous observation and training are important in developing an intelligent chatbot.

Conclusions

This research project involved the design and development of a chatbot to respond to current and prospective student queries for Eastern Illinois University. The chatbot is still in a testing phase. To make the chatbot smarter and perform intelligently, developers must train it using a significant amount of data. Initially, it is a bit challenging to depend totally on a chatbot to solve user questions, so it is recommended to continuously monitor chatbots.

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SURVEY OF GPU VULNERABILITIES AND FORENSIC SCIENCE

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Abstract

The world is changing together with technology and the way in which computers are used. In this paper, the authors address three areas of computing. First, graphic processing unit (GPU) architecture is discussed, explaining how GPU memories and the application program interface (API) are connected. Second, the vulnerabilities, threats, and risks of GPU memories are covered to show the importance of the security aspect in the GPU. The notion that using GPUs as co-processors with distinct memory spaces will be challenged. Furthermore, the research shows that various security risks exist in GPU infrastructures, such as denial of service attack, Jellyfish malware, information leakage, and the use of GPUs to further CPU-resident malware. Third, the authors cover the legal and technical hurdles that forensic investigators face when performing forensic analysis on volatile memory and volatile data. Also presented are the forensic tools used for forensic analysis and hints for a possible solution to address the need for GPU forensics.

Introduction

The fact that computer games are diversifying and gaining a competitive edge over their rivals is important for vendors; therefore, provision of high capacity for better video and image architecture is of great importance. The CPU can perform all of the processing functions on its own, but adding a GPU gives the user a dedicated section for graphics. Manufacturers of mobile phones and computers are competing to have the best systems for their customers. Advancements in technology have created powerful GPUs that increase the quality and reduce the processing time of images and videos. Graphics development does many computations over a short period; thus, sufficient resources need to be allocated to image and video development. GPUs were initially designed using the graphics and design pipeline idea, and they supported a select few fixed-function pipelines.

The hardware gradually became programmable with the capacity to support high-performance software. The change from 3D space to a 2D pixel area on display interfaces increases the vulnerability rate and this, in turn, threatens the operating system. The outcome is potential leakage of crucial data, improper calculation results, and reduced accessibility of the GPU and other parts of the system. GPU vulnerabilities are classified into those that influence the applications operating on unprotected GPUs and those that can compromise the entire system.

Forensic science is the use of science in civil and mainly criminal law during a criminal investigation, as dictated by the legal paradigm of acceptable evidence and criminal procedure. Forensic scientists gather, store, and analyze scientific data during the research process. Recent decades have seen advancements in forensic science, and nowadays many countries embrace it as a major component of a modern legal practice. Forensic investigations have been used in many cases as a primary source of evidence to determine the outcome of a verdict. As technology evolves, forensic scientists have established new practices in the law realm; hence, forensic science has become a routine part of the investigation for criminal cases in America. In this paper, the authors discuss GPU architecture and GPU security issues in detail to show where GPU forensics are needed. The connection between the GPU's APIs and GPU memories are addressed, as well as several GPU security issues and GPU attacks. Challenges such as memory acquisition in GPUs are presented in order to identify obstacles in GPU forensics. Lastly, the technical and legal challenges in GPU forensics are addressed.

Contributions

The result of this study was, to the best of the authors' knowledge, the first of its kind to link GPU vulnerabilities with forensics. The authors go on to 1) discuss possible solutions that address the needs for forensics in GPU; 2) present possible gaps in GPU forensics; 3) present the different types of memories and data used in the GPU; and, 4) present a detailed structure of the GPU and how the process flow works.

The GPU Architecture

With 3D images and video games, the GPU has become a useful part in the performance of computers. Their architecture is suitable for the algebraic calculations required in the computation of images. Programmers can communicate with the GPU using APIs, such as Open Computing Language (OpenCL), Compute Unified Device Architecture (CUDA), and DirectCompute. As computers become a part of the human experience, the GPU application in videos has improved the experience of the players of 3D games. GPU architecture differs from one GPU to another; for example, the NVIDIA company has over eleven different GPU architectures. The first GPU by NVIDIA was called the NV1 family and was released in 1995. The latest families are Maxwell, Kelper, Fermi, and Pascal. Figure 1 shows the architecture of the Fermi family GPU, which consists of multiple streaming multiprocessors (SMs). Each SM has 32 cores and is supported by multiple DRAM interfaces, a GigaThread scheduler, and an L2 Cache (Glaskowsky, 2009).

A single SM can handle up to a thread block of 1536 threads. Thread blocks share the use of global memory. The order of the threads can be executed concurrently or sequentially. All of the threads are managed by the chip-level GigaThread hardware scheduler to enable fast switching between applications. The L2 cache in a GPU has a unique atomic operation such that read-write-modify operations are not interrupted when accessing shared data between threads (Glaskowsky, 2009). The Fermi family is considered the first complete NVIDIA GPU, because it contains all of the necessary components demanded by high-performance computing (HPC) applications (Glaskowsky, 2009). Some of the features are 1) support for multiple languages—such as C, Java, and Python; 2) error-correcting code protection; and 3) a linear addressing model.

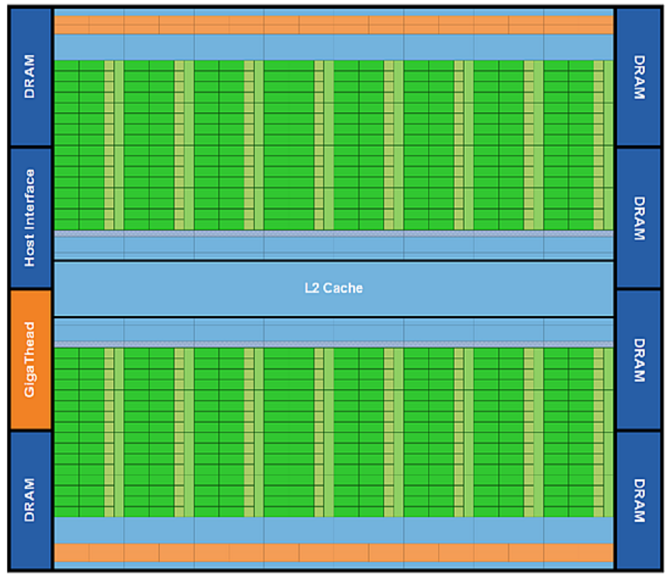

Figure 1. Fermi GPU Architecture. Reprinted with permission.

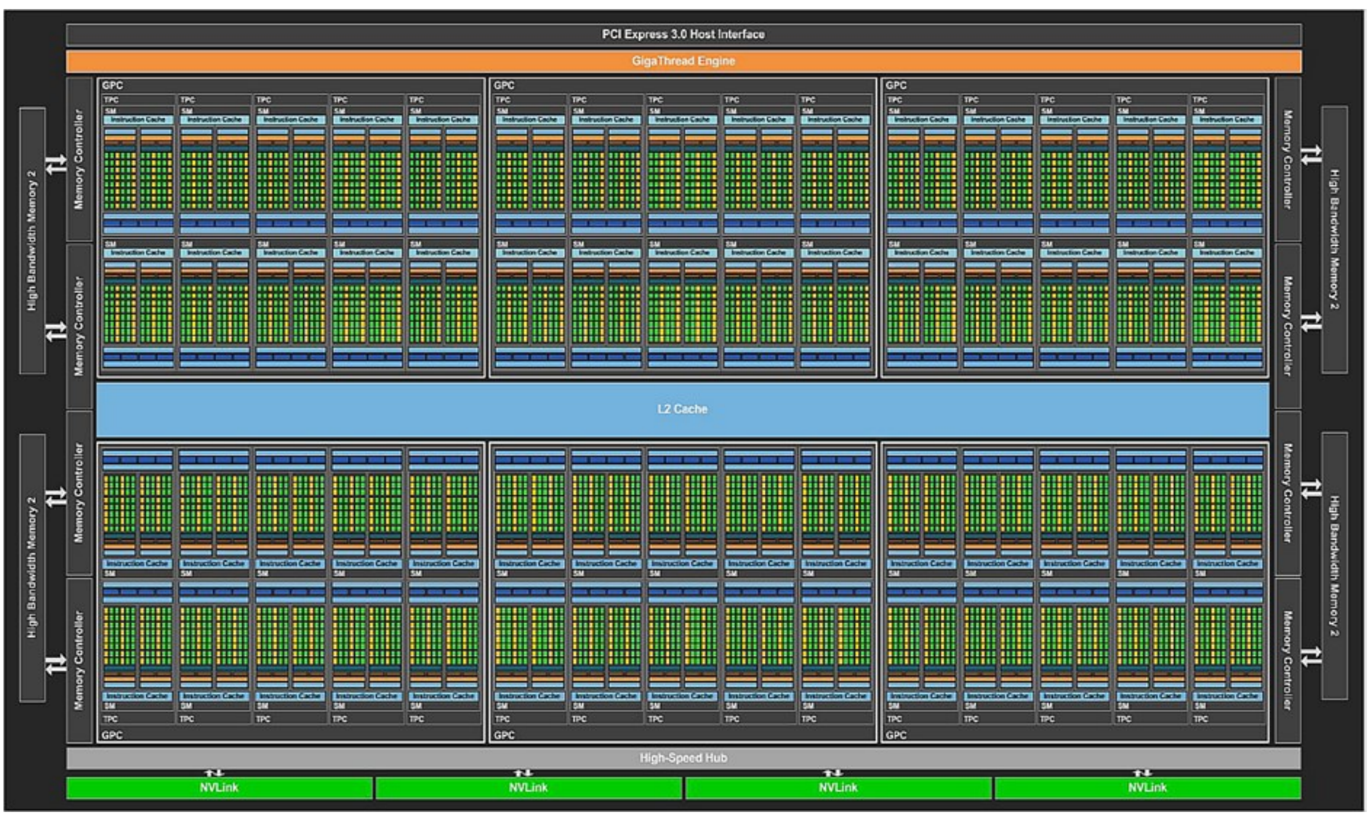

Figure 2. NVIDIA Pascal GP100 with 60 SM Units. Reprinted with permission.

In the Fermi family, each SM includes 32 CUDA cores. Each core implements one operation in every clock period. Sixteen storage units handle the memory operations and provide *x* and *y* addresses. Special operations, such as sine and cosine, are operated by the four special function units (SFUs) (Glaskowsky, 2009). The Pascal family is considered the latest NVIDIA GPU, as it was released in early 2016 (NVIDIA, 2016). The Pascal GPU architecture shown in Figure 2 contains 60 SMs, which is more than double that of the Maxwell GPU. This significant number of SM is needed in order to increase GPU performance and enhance power consumption (NVIDIA, 2016). When comparing architectures, for instance the Pascal and Maxwell families, it should be noted that although Pascal has fewer CUDA cores in each SM—about 50% fewer—it still holds the same size register file and overall capacity. Pascal architecture simply decreased the number of CUDA cores and increased the number of SMs, which gives the advantage to the GPU to handle even more registers than Maxwell and Kepler (NVIDIA, 2016).

GPU Memory Processing, Access, and Allocation

The operation of the GPU is based on the conversion of numbers in the visualization and computations to obtain an image. With the resource requirements in the graphic computations, the GPU uses its memory and that allocated to its operations in the system. The allocations of the memory are all based on the properties of the specific GPU. A GPU has its dedicated memory that is available for the graphics development, based on the capacity of its computations. If the company producing the product allocates 256MB, the GPU can have all of this memory at any time in the computations (Di Pietro, Lombardi, & Villani, 2013). The system memory is allocated to the GPU based on the way these organizations predict the need for this memory. The computations in the system depend on the nature of the objects being processed, and any increase in the memory requirements calls for more from the system (Su, Chen, Lan, Huang, & Wu, 2012; Marziale, Richard, & Roussev, 2007).

Modern GPUs and APIs

Modern GPUs allow programmers to improve the content of their software to meet the needs of the users. In the development of modern GPUs, the performance of the system allows users to modify the memory needs of their programs and improve the performance of the system. As the use of computers has increased, more people have gained interest in 3D games that require high-quality images. The dedicated processing unit allows users to receive quality images and still have their personal computers running smoothly. There are two major platforms that are useful in the development of the APIs to improve the graphical interface and maintain the personal computer's performance (Su, Chen, Lan, Huang, & Wu, 2012; Marziale, Richard, & Roussev, 2007). With the increasing capability of programmers to modify their GPU's performance, researchers have set out to investigate the effectiveness of the available programming platforms. In the development of the APIs, the software developers could use CUDA or Open Computer Language (OpenCL), depending on their needs (Su, Chen, Lan, Huang, & Wu, 2012).

The CUDA application is specific to NVIDIA GPUs and allows users to reprogram their interface based on their needs or requirements. The users of GPUs who intend to use this platform must purchase the CUDA-enabled type when installing their graphic systems. The effectiveness of the GPUs depends on the way the users make the necessary changes in the applications (Marziale, Richard, & Roussev, 2007). The programmable applications of the GPU allow software engineers to use their knowledge to develop the graphic applications that suit them. CUDA is one important platform that has improved the experience of graphic design (Farrugia, Horain, Guehenneux, & Allusse, 2006). The register's memory is read/write, thereby allowing editing to meet the needs of the programmers. The case applies to the local memory that is accessible for editing and reprogramming for the benefits of the users and the game developers. The shared memory can also be edited during the development of the best software programs for the users (Su et al., 2012). The shared memory, the local, and the register memory are part of the grid memory in the CUDA systems. With programming capabilities, programmers can decide the types of applications that they need to meet the requirements of the system. Management of these platforms is performed by the users who must come up with the most critical applications of the users. Any changes must be made based on the newest applications that must be made to meet the requirements of the programs. The constant memory of CUDA cannot be changed during the re-programming, and it is a read-only memory that the programmer must use (Su et al., 2012; Marziale, Richard, & Roussev, 2007).

CUDA has two different APIs, the CUDA driver API and the CUDA runtime API. When invoking kernels, or allocating host or device memory. CUDA driver API is preferable when working with hardware resources of the GPU, such as device management. The CUDA memory model is similar to the OpenCL memory model. The only difference between OpenCL and CUDA memory models is that the OpenCL has private memory, while CUDA has a shared memory (Su et al., 2012).

OpenCL is an API by Khronos that works on an open standard platform allowing use with most of the GPU programming properties. The major difference between CUDA and OpenCL is the programming interfaces that determine the application of the APIs on different processors. OpenCL is more portable and useful in terms of performance on different platforms and computers. The developers of graphics can rely on this interface for the processing requirements that can be used on different GPUs with less modification (Karimi, Dickson, & Hamze, 2010). OpenCL works on four virtual memory regions, where each holds different types of data. In view of these developments, a programmer must decide on the requirements and the adjustments that have to be made and the point of access to the changes. Allowing for re-programming has improved the interaction between the features available and the needs of the users (Su et al., 2012; Du, Weber, Luszczek, Tomov, Peterson, & Dongarra, 2012).

In OpenCL, global memory is the region where the primary code of the interface is stored for running the programs. Since this memory is in read/write format, it can be edited to meet the needs of the media and the personal computer in use. The constant memory allows users to view content that they cannot edit or make changes to. As its name indicates, this memory maintains its contents (Munshi, 2009). The OpenCL platform has a local memory that is accessible for viewing and editing to make changes for improvement (Munshi, 2009). It is important to note that the local memory is linked by a work-group that consists of a work-item that consists of processes executed as one unit. The private memory holds the values of the kernel process that is executed by the processing elements. The changes in this area are as frequent, as the computer is used for different tasks. These values are stored on the C66 DSP stack of the L2 memory (Munshi, 2009).

Connections between the GPU Memories and the APIs

In the operation of GPUs, the computer kernel defines the exact routine through which the sub-tasks are shared and distributed in the operating systems. The exact quality of the output depends on the distribution of resources available for the computation of the GPU. These changes in the operating structures determine the performance of the system and the allocations to the dedicated activities. The re-programming feature allows the users to develop adequate methods of creating the required output from the image development features. The API is the connection between the operation of the GPU and the software engineer making the changes to fit the current source requirements. With the right API, software developers can use the GPU to meet their exact needs, based on the requirements of the job at hand. The API follows the general-purpose graphics processing units (GPGPU), where general processing can be influenced by the user (Vasiliadis, Polychronakis, & Ioannidis, 2015).

The GPU memory is divided into sections that can be edited based on the features available for the processing activities. The editing features further depend on the changing needs of the users, GPU manufacturer, and the type of the API applicable to that GPU. The basic operations are stored in the constant memory of the API, and the users cannot make changes to the existing files (Du et al., 2012; Podlozhnyuk, 2007). The role of the API is to connect the individual to the properties of the computer that fit the data editing requirements of their system. The actions of the software developer depend on the choice of the API that they decide to use for the sake of the computations. These developments require a system that allocates the necessary resources to the tasks at hand. An API allows the user to access the memory of the GPU and make the required changes (Farrugia et al., 2006; Stirparo, Nai Fovino, & Kounelis, 2013).

Another role of the API is to connect the operating system to the GPU, where the information on the graphics is collected. The computational role of the system requires the collection of the relevant data for processing and passing to the CPU. The operation of these systems depends on the underlying operating system and the capabilities of the hardware elements (Qin, Lu, & Zhou, 2005; Power, Hestness, Orr, Hill, & Wood, 2015). The applications specified by the users are entered into the GPUs through the APIs, depending on the choices of the users and hardware requirements (Power et al., 2015). The GPU makes changes to the system by allowing the applications to share the resources and move the processing activities through the right sequence. The basic flow of information between the applications and the GPU requires the existence of a matching API. Examples of software include 3ality Intellicam, 3DAlliens, Glu3d, and the ABSoft Neat Video that have been modified to improve the performance of the GPU. With these applications, computer users can modify their GPUs and computers to meet their unique demands in image development (Bellekens, Paul, Irvine, Tachtatzis, Atkinson, Kirkham, & Renfrew, 2015).

GPU Security Issues

Security vulnerabilities in GPUs can be the gate to severe threats, especially when there are no security measures applied; for example, information leakage, memory degradation, crashes in systems, and denial-of-service attacks (Patterson, 2013). It is especially troubling that a few security vulnerabilities in GPUs influence procedures and processes that are never executed in the compromised accelerator. For instance, a GPU that is permitted to have unrestricted access to bound unified system memory could mishandle this privilege by checking for sensitive information in the memory. In addition, it could bring about reliability and quality issues by performing unauthorized and wild executions (Junkins, 2015). Likewise, a compromised GPU could corrupt execution of other system segments (Lee, Kim, Kim, & Kim, 2014; Callan, Zajić, & Prvulovic, 2014). Moreover, as demonstrated by the well-known Pentium FDIV bug, bugs bringing on wrong executions can happen. Developers should understand the risks and guard against them using various strategies, including checking computer system action for indications of malignant conduct and developing safe interfaces to shared computer system resources (Ozsoy, Donovick, Gorelik, Abu-Ghazaleh, & Ponomarev, 2015).

To this end, there is a need to break down risks by considering GPUs in SoC (System-on-Chip) schemes. The aim is to make it less challenging for system architects to make educated, security-cognizant decisions, when incorporating GPUs into their designs. Besides, a discussion on the various conceivable risk classifications that may be available in the GPU, besides their outcomes, is prudent (Junkins, 2015). The scientific classification of vulnerability, threat, and risks for GPUs covers the major classes of vulnerabilities. This approach is essential, since it does not force developers and designers to consider each conceivable risk separately. Besides, it permits risks to be arranged according to the segments of the system that are affected as well as the security properties they abuse. In spite of the fact that the major focus is on accelerators in regard to GPUs, large portions of the risks that affect accelerators and, in turn, GPUs are important for different types of the third party outsider IP. There is a critical differentiation between security risks that are internal to the influenced GPU, which affect applications running on that GPU, and those that affect different parts of the system. A case of a risk at GPU range is leakage of data between two procedures running simultaneously on a similar GPU, which can be brought about by the absence of security to the GPU's internal memory. Moreover, vulnerabilities at system scope influence parts of the system past the compromised GPU. Likewise, they influence accurately executed parts of the system. A case of a system scope risk is inappropriate access to a sensitive address in system memory.

Cases of vulnerabilities can be separated into threats at the GPU and computer system scope. For instance, misconfiguration of confidentiality can lead to fewer iterations than anticipated. Kleptography (Stirparo, Nai Fovino, & Kounelie, 2013), permits texts to be encoded in a manner that only a secret "big-brother" key can decode. Besides, misconfiguration of integrity can bring about incorrect results. Furthermore, some gadgets, hardware, and devices might be misconfigured, which may make the host fail to discover them. In evaluating termination, confidentiality after the termination of a program can be compromised when leakage of data happens if registers, internal memories, or other states are uncleared. A known case of this for GPU memory exists (Lee et al., 2014). Furthermore, translations of addresses could prompt vulnerabilities; for example, restricted access to computer system memory. While evaluating integrity, translations of addresses that is stale can be a source of computational results that are faulty. In regard to accessibility, the failure to discharge GPU resources stops different procedures from running.

In the scope of accelerator memory access, and in regard to confidentiality, integrity and availability, a GPU that permits one process running on the GPU to access GPU memory already claimed by another procedure running on the GPU can lead to data leakage. Di Pietro et al. (2013) exhibited this abuse on certain GPUs, where pieces of the two procedures are interleaved. Besides, a GPU permitting simultaneous execution of procedures to keep in touch with each other's GPU memory may have accuracy mistakes. Furthermore, if different processes are running simultaneously, where one is permitted to have preference over the GPU resources, the other may experience the ill effects of degraded execution. For instance, if one process can remove all cache sections allocated to the other, the compromised GPU will endure execution penalties.

With regard to power confidentiality, the power utilized by the GPU can be utilized for side-channel assaults; that is, assaults of power analysis (Di Pietro, Lombardi, & Villani, 2013; Dang, Gazet, & Bachaalany, 2014). Such cases are pervasive and incorporate assaults against GPUs for AES (Advanced Encryption Standard) (Engel, 2004). Many researchers focusing on the subject of GPU vulnerabilities provide solutions to these problems. To this end, the scientific categorization of risks and threats affords computer system developers a method of permitting GPUs to accurately consider the security ramifications of their design decisions. No exhaustive scientific classification is comprehensive enough to cover all the vulnerabilities. This issue arises because it is not conceivable to develop risk classes that one has not considered; for instance, programming researchers may fail to consider coherence exploitation in impeding accessibility and availability.

Nonetheless, such a scientific classification can be valuable in different ways. First, building up a scientific classification can give a jumpstart towards a GPU security standard. Secondly, this structure can permit developers to consider the main classes of potential assaults, instead of centering on each vulnerability in turn. Thus, a method is provided for proactively planning preventive and defensive measures, which prompts fewer vulnerabilities in third party -shipped equipment. Developers will have the capacity to think carefully about risks and guard against them by employing various strategies. These measures include checking computer system action for indications of malignant conduct and developing safe interfaces to shared computer system resources such as memory and hierarchies in cache (Ozsoy, 2015). What's more, the scientific categorization and the differentiation between interior and computer system threats will permit developers, both of applications and operating systems, to systematically evaluate the risks of running crucial and sensitive applications of third-party GPUs as well as other accelerators that have not passed validation checks, since they cannot be trusted.

Detailed Analysis of GPU Memory Vulnerabilities, Threats, and Risks for Denial-of-Service (DoS) Attacks

A large proportion of consumer GPUs function as coprocessors to the host CPUs (Patterson, 2013). The GPU in such configurations executes tasks arranged in a series. It is impossible to halt or preempt tasks without having to reset the device. A key task of a GPU in many systems is to draw the operating system (OS) desktop and interface. Patterson (2013) indicated that the GPU does not have the capacity to update the user interface while it is processing a task. The client faces an unresponsive system when the task takes too long to execute, which causes DoS vulnerability. Attackers can easily exploit this vulnerability by overtaxing the GPU. An easy way to do this is by utilizing standard graphics APIs such as DirectX or OpenGL (Patterson, 2013). WebGL allows browsers to access GPUs to ensure that a site exploits their processing capabilities. This can act as an extremely risky attack vector, because attackers can launch these deliberate exploitations remotely once an unsuspecting client visits a malicious IP address, domain, or website.

Most platforms do not support WebGL, since it is a relatively new technology. Although the newest versions of Chrome and Firefox support WebGL, the newest versions of Internet Explorer do not. Similarly, no version of Safari provides WebGL support, although users can activate it manually. Likewise, even the main mobile browsers do not support WebGL. However, this situation is likely to change in the coming years. In fact, WebGL support is a key component of the mobile version of Safari, although developers have not activated it officially. This issue is evident in the mobile versions of Firefox and Chrome, because the desktop browser codebase has WebGL support that developers have not enabled. Unquestionably, both iOS and Android devices, which are featured in most cellphones, will soon support WebGL. Patterson (2013) conducted an investigation by testing the desktop versions of Safari, Chrome, and Firefox, because they are the only browsers that fully support WebGL. The results showed that all browsers responded to these attacks the same way. Following the successful attacks, total OS freezes would occur. Consequently, the entire OS would become unresponsive and it would be impossible to redraw anything on the display.

Memory Vulnerabilities: ASLR and Process Isolation

Address space layout randomization (ASLR) is a security technique that is designed to make it more difficult to exploit volatile memories. ASLR achieves this by positioning different data areas randomly within the address space of a process. Process isolation is a central component of computer security. The basic concept is that every process on the operating system needs to be protected from the other processes. Specific channels may be provided to enable interprocess communication; however, it is inappropriate for one process to write or read the memory contents of another process or otherwise affect its execution. Most modern OSs and CPUs carry out process isolation by combining ASLR and virtual memory. Patterson (2013) demonstrated the way virtual memory addresses aid memory isolation for every process. The translation of each virtual address utilized in a process into a special physical memory address occurs through a page table. Consequently, process A and process B can both utilize memory address `0' with no memory leakage or collision in the process. Developers have included ASLR in the most common operating systems. Due to ASLR, information leakage between processes would be virtually impossible, even if there were no process isolation. An attacker would have to guess the location of the required data every time an attack is executed. Although it is possible to implement this, and brute force attacks can take place, it is extremely difficult compared to simply knowing the location of crucial data in the address space of a program.

At present, there are no GPUs that implement either ASLR or virtual memory. Importantly, memory address '0' represents the same memory location in all processes. When process A employs a pointer to the address that process B has previously utilized, it accesses the specific physical memory that process B used. The issue may appear to pose no major problems, because current GPUs execute processes sequentially. However, the mentioned vulnerabilities only exacerbate the matter, and a person can exploit the vulnerabilities. Currently, ASLR is not a component of modern GPUs. As a matter of fact, pointer allocations constantly return the same addresses, and this implies that there is no randomization of the key data areas. Moreover, GPUs never zero out memory after deallocation or before allocation. This issue is further complicated by the lack of ASLR as well as virtual memory, which causes an evident vulnerability for leakage of information. Since pointer allocations have not been randomized, it is possible to determine the addresses of different data. Moreover, since there is no virtual memory, the addresses have access to the same physical memory from different processes. The data stays in the memory after the completion of program execution since it is never cleared.

Hackers can carry out data leakage attacks using numerous methods. However, Patterson (2013) explored proof-of-concept attacks and showed how an individual can exploit these vulnerabilities and leak data from a particular CUDA program into another. Patterson also used two CUDA programs to demonstrate and test this attack. First, savekey.cu, a program responsible for assigning memory on the GPU, storing the value 95.0 in the memory, printing the stored value, and releasing this memory on the selected device. During the testing process, the program acts as the victim that discloses data to the attacker. Second, getkey.cu, a program designed for assigning a portion of the memory on the GPU, copying the stored information to the CPU, printing the recovered value, and releasing the memory on the chosen device. More importantly, the specific area in the GPU memory under attack or from which information is accessed is not initialized. During testing, this program acts as the attacker, since it helps in recovering the value stored by the earlier program on the GPU. Once the program retrieves the correct value, which was 95.0 for this event, this attack has been accomplished and the information leakage has occurred.

Results

As can be predicted from the vulnerabilities, the authors were able to demonstrate data leakage from one CUDA application to the other. The attack on the system was successful, because the leakage of information occurred from the program's execution of the savekey to the execution of the getkey application (Patterson, 2013). The episode was an excellent demonstration of the vulnerability of information leakage between the CUDA programs. Moreover, the attack was successful in different login sessions and while using multiple users. There exists no automatic method of clearing the GPU memory. Consequently, information can remain in the GPU memory for a relatively long time, and any person who knows its location can easily read it. Although such proof-of-concept attacks do not pose significant harm, they can lead to serious consequences. GPU hardware and software do not provide memory protection. As a result, all forms of data processed on the GPU are susceptible to leakage.

Several years ago, the issue would have been insignificant, because games were the main applications that required a lot of processing on the GPU. However, this has changed since then, because people use GPUs for crucial processing. In fact, more people are likely to adopt the use of GPUs in the future. At the moment, there are many applications in government contracts, commercial ventures, and scientific research. In fact, Google Chrome permits the rendering of entire web pages utilizing the GPU in addition to WebGL content. Thus, sensitive materials, including valuable bank account information and research data, are vulnerable if users do not implement individual security measures for software.

GPU-Assisted Malware

Besides the afore-mentioned vulnerabilities, a person can use a GPU to aid traditional malware. The main benefit of using a GPU is that it is impossible for the CPU to scan a code that executes on a GPU. Furthermore, security software cannot analyze GPU binaries. Consequently, current anti-virus software does not provide a safeguard against any malicious CUDA codes. Since CUDA software never requires elevated privileges, a person can launch it. Additionally, the application is essentially stealthier because it is more likely that a large number of users can notice or monitor a spike in the usage of a CPU, but fail to notice one in the use of GPU.

Potential Attacks

Vasiliadis et al. (2015) described numerous strategies utilized by authors of malware to prevent detection, which focused on runtime polymorphism and unpacking. They explain how CUDA can assist in enhancing these strategies for the execution of major functions on the GPU. Importantly, the GPU has the capability of improving the unpacking strategy, because of the inability of analysts to scrutinize CUDA binary files as well as the GPU's computational performance. It is feasible to employ complex encryption schemes to hide the malware contents, because the GPUs' power facilitates faster decryption compared to those of CPUs. As a matter of fact, the host code only loads the encrypted information to the GPU and calls the GPU function that unpacks the appropriate code. The approach aids in minimizing the level of host malware codes accessible to security investigators, because the binary code of a GPU is fundamentally a black box. Such functionalities would provide insignificant benefit if a person implemented any form of run-time polymorphism. Following the completion of the unpacking phase, the original code of the malware remains in the host memory, which makes it vulnerable to all kinds of analysis. Consequently, numerous malware authors carry out run-time polymorphism simply by unpacking a chunk of code sequentially. Besides, it is possible to implement this procedure on the GPU to enhance results. As a result, it would lead to malware that is extremely difficult to detect and reverse engineer.

Stewin and Bystrov (2012) discussed the likelihood of attacking systems by capitalizing on direct memory access (DMA) to get the right of entry to memory that would have been protected. It is worth noting that the extension of this concept to GPUs can be a sensitive vulnerability. DMA permits the access of a GPU to system memory without any influence from the CPU. Because the CPU is responsible for the protection of memory, the DMA can bypass any form of memory security and give room for unrestricted access to the system memory. Stewin and Bystrov (2012) further described how people have implemented this kind of attack successfully through the use of network cards. Currently, it is virtually impossible to employ GPUs to execute such attacks, due to the manner of DMA implementation in CUDA.

It is almost impossible to utilize DMA without having various asynchronous copy functions. Importantly, the CPU allocates host memory and the pinned memory, which is transmitted to the GPU for utilization in DMA. The process helps in preventing vulnerability, because the protections remain in the system and the CPU continues to control the memory access. The GPU is capable of only using DMA for accessing the memory that the CPU allocates to it, and it cannot utilize the system protected memory. Possibly, a GPU might have increased control over its DMA in the future; however, it is currently impossible to execute this kind of attack.

Vasiliadis et al. (2015) highlighted the framebuffer, which is located in the GPU memory, as a possible attack vector. Thus, theoretically, an attacker can design a GPU program to access this component for malicious motives. The program can perform as a stealthy screen grabber after grabbing the contents. Besides, individuals can use it in advanced phishing attacks by examining current displays and changing certain regions within the element. For instance, it could evaluate the addresses of browsers and replace the actual addresses with fake ones. Consequently, it would cause phishing attacks that are difficult to detect. However, it is impossible to implement such attacks using existing GPU programming APIs. Although the framebuffer resides on the GPU, APIs cannot allow a programmer to access it directly. In fact, CUDA does not have the capacity to write directly to the framebuffer or read from it. While it is possible to add this functionality in the future, it is not currently present (Patterson (2013). Nevertheless, a GPU can be valuable in a similar attack. Specifically, it can aid screen-grabbing malware in numerous ways. For instance, it can scrutinize the captured screenshots to assess whether it has useful information. Since such investigations would be computationally intensive, it is more appropriate to execute the process on the GPU, which would not take up CPU cycles or slow the device. Besides, the GPU can assist in encrypting or compressing the image before its transmission. Such operations map well to the parallel architecture of the GPU. As a result, this approach can lead to malware that the average user cannot easily detect.

People have leveraged GPU computing to gain unauthorized access to password hashes through brute force. Patterson (2013) showed how GPUs can generate hashes many times compared to CPUs, which can cause a decrease in the number of times needed to crack a password. It is possible to use this capability to make malware more efficient in accessing escalated privileges and sensitive information. Host code can quickly access hashes of user passwords and crack them on the GPU in the background. As a result, this would significantly reduce the time required for cracking and prevent the increased usage of the CPU that usually reveals when malware is present. Likewise, a person can employ the same approach to decrypt files on the computer of an unsuspecting victim.

Botnets are core components of computer security. Such interconnected networks of computers are responsible for the majority of spam email, malware distribution, and DoS attacks. Botnet operators employ different techniques to ensure that they are harder to detect and more effective. Most of these strategies can gain from GPU computing. For instance, an individual can increase the robustness of botnets by using the dynamic calculation of control servers and command. The calculations usually occur on the CPU of the bot; however, it is possible to accelerate them through the use of the GPU. As a result, this could permit the use of more advanced schemes, which would make them extremely hard to predict. Likewise, a person can take advantage of the power of a GPU in encrypting the communications between the control server, the command, and a bot (Patterson (2013). Besides, he or she can utilize a more sophisticated encryption plan to increase security, which would make the host available to carry out other tasks. Besides, an individual can leverage distributed GPU computing to complete activities like bitcoin mining or distributed password cracking.

Jellyfish is a malware that was designed by anonymous developers using a Linux-based operating system. Its codes currently support AMD and NVIDIA graphic cards. The malware uses the driver tools associated with these graphics cards such as CUDA to navigate to the GPU (Ladakis, Koromilas, Vasiliadis, Polychronakis, & Ioannidis, 2013). The rootkit Jellyfish, the keylogger Demon, and the remote access WIN_JELLY have been said to represent proof of the concept. This is as per their developers. Tapping an infected system can allow the malicious software to operate within the system (Ladakis, Koromilas, Vasiliadis, Polychronakis, & Ioannidis, 2013). Jellyfish malware leverages GPU memory to hide the presence from antivirus or any other system protection using root-kit techniques and keep records of any data typed in by keystroke in the computer (Ladakis, Koromilas, Vasiliadis, Polychronakis, & Ioannidis, 2013). The study by Ladakis et al. (2013) revealed that keylogger malware can effectively store and analyze the keystrokes from users utilizing the memory space of GPUs, while only consuming an untraceably small amount of memory resources for its operation.

Traditional DMA side-effect observation-based detection will not work in identifying the presence of keylogger malware, as it does not perform any noticeable DMA transfer. On the other hand, GPU utilization profiles and access patterns might provide a better way for detecting the presence of such malware. One proposed approach for detecting the presence of keylogger malware is to constantly monitor for any traces in CPU memory, because, as a limitation, it requires CPU processes to trigger malicious a GPU kernel. However, a CPU memory-based detection technique would have to be extensively meticulous, because the keylogger leaves a negligible CPU footprint, on the order of 4 KB or less, while executing its processes (Ladakis, Koromilas, Vasiliadis, Polychronakis, & Ioannidis, 2013). The jellyfish malware utilizes an existing benign user-level process to hide its CPU component in the address space. This is why GPU memory-based keylogger malwares are largely successful in keeping their identity hidden from most of the common detection techniques and are capable of stealing sensitive information from the users' computer performing in-place analysis of the data stored from keystrokes. It utilizes only 0.1% of CPU and GPU resources (Ladakis, Koromilas, Vasiliadis, Polychronakis, & Ioannidis, 2013).

Forensic Science

With the growing rate of criminal activities, forensic science has gained ground, due to the absence of witnesses or false witness testimonies (Ellick, 2001). Drug-related and sex crimes are the most common offenses, where forensic science can help narrow down the perpetrators. Forensic toxicology determines the level of intoxication of a person, in the case of an accident and poisoning in death cases. DNA evidence from the victim can help identify the criminal responsible for the sexual or physical assault (President's Council, 2016). Weapon analysis and ballistics are part of forensic science. Forensics experts use their ammunition knowledge and study the bullet's impact in order to determine the position of the shooter, the number of shots the shooter fired, and the kind of gun the shooter was using (Ellick, 2001). Forensic experts search the databases, trace the IP addresses, and retrieve documents from electronic devices to identify the criminals. The increase in cybercrimes has resulted in the development of cyber forensics.

Cyber Forensics

Cyber forensics is the acquisition, authentication, analysis and evidence documentation process retrieved from online or offline systems (Information, 2004). The systems could be from computers, digital media, networks, or storage devices that could contain valuable information for investigators Data or file carving techniques are commonly used by computer forensic experts to extract digital evidence from a source. Computer forensics is significant not only because of its ability to recover files that are hidden or deleted from the systems or storage devices, but also because it can inform forensic experts when the systems were interfered with or that other suspicious activities had occurred. According to the Information Security and Forensics Society (2004), computer forensics has helped solve the challenge of information recovery from files where the structure of the file system was corrupted or the file system was unavailable. Criminals may delete suspicious files or format the system to conceal their activities; however, with modern technology, cyber forensic experts are able to retrieve each and every file from electronic devices or online.

Cyber forensics began in 1970. Then, by 1984, law enforcement agencies had developed forensic applications to examine the computer evidence. To satisfy a growing need for computer forensics, the Federal Bureau of Investigation set up the Computer Analysis and Response Team (CART) for the purpose of analyzing the computer evidence. Following the success of CART, other law enforcement agencies followed suit and established forensics departments (ENFSI, 2009). The examination of forensic evidence is carried out in forensic laboratories by computer forensic investigators. A skilled forensic expert is the best at examining forensic evidence, as it is important to preserve data integrity. Many forensics experts follow their own procedures and standards on computer forensic examinations, which can lead to inconsistencies in their results. Having multiple sets of standards could jeopardize the credibility, integrity, and validity of digital evidence (Yulong, 2015). In an attempt to create a consistent set of practices, in 1991, law enforcement agencies made suggestions on how to standardize and streamline the forensic evidence examination process, leading to the creation of the International Organization of Computer Evidence and Scientific Working Group on Digital Evidence (Information, 2004).

With advancements in technology, online criminal activities have also increased. Criminals have gradually learned to use technology to hide their illegal activities. The loss of billions of dollars to cybercrimes emphasized the necessity for developing practical digital forensic tools. Cyber forensics is growing in significance for law enforcement agencies because the computers and the internet are the rapid growing tools of technology the criminals use and the trend will continue to rise due to continued advancement in technology. The internet is a challenge for legal investigations, the issue being jurisdiction. Crimes, including theft, phishing, scams, and fraud, are all possible to carry out through the internet, making it possible for criminals in one country to commit a crime against a person in another country using the servers in a third country. The internet is also changing crime scene investigations. Criminals have become smarter in using the same technology they use in committing an offense in covering their tracks (Information, 2004).

Before carrying out a full cyber forensic investigation, it is important to undertake measures to ensure that the results to be used in court are desired. The most significant measure is to make sure of the precision of the evidence gathered with a clear chain of custody. The chain of custody needs to show the documentation of the evidence from its collection from the crime scene until its presentation in court. The evidence collected at the scene of the crime is sealed to prevent contamination and tampering with the data to preserve its integrity. When the chain of custody is broken, or in the event of contamination of the evidence, any piece of evidence that the forensic experts may find is not valid in court. Therefore, it is essential for investigators to follow the guidelines for procedures to ensure the evidence remains uncontaminated (Information, 2004; ENFSI, 2009).

Following are the principles of cyber forensics. Law enforcement agencies or the investigators must not interfere with any of the evidence gathered from storage devices or computers that are to be handled in court. Second, on the occasion where an individual wants to access the original data from the storage devices or the computers, this person must be forensically competent to be able to explain the relevance and implications of the evidence. Third, cyber forensic experts must fully document as well as preserve an audit trail with all of the processes and procedures carried out on digital evidence. Finally, the investigator or the law enforcement agency in charge has the responsibility of ensuring adherence to these principles (Workshop, 2001). Digital evidence is the outcome of cyber forensics.

Digital Evidence

Digital evidence is a soft copy form of evidence. Digital evidence is any digital or electronic information that forensic experts retrieve and obtain through electronic or digital media, and which can be used as evidence in court (Workshop, 2001). The court determines whether the digital evidence is relevant, hearsay, or authentic, and if it needs the source. It can be any data format type, including word processing documents, Excel spreadsheets, internet histories, computer logs, electronic images, emails, digital videos, mobile messages and call logs, instant messages, and GPS tracks (National, 2003). Social media, for instance Twitter and Facebook, may all provide important digital evidence. Digital evidence differs from physical crime evidence in a number of ways. Physical evidence from the crime scene is durable and can be kept with the camera for later analysis, whereas with digital evidence any wrong move might destroy or alter the evidence.

Digital evidence is fragile and easy to damage, modify, or destroy. For this reason, experts often duplicate the original evidence and carry out the analysis on the copy so as to prevent damaging the original document (Workshop, 2004). The scope of digital evidence examination is wide; it can be offline or online, for example, and involve credit card transactions, hard drives, and internet communication history. Digital evidence is vital to some investigations, since it may indicate the sequence of events and pieces of a criminal activity, thus informing investigators of the offender. The system records every click on the computer and a forensic expert can uncover what kind of activity the user of the system was engaged in. Forensics experts look for forms of metadata, hidden data, and suspicious content on the hard drive (National, 2003).

In collecting digital evidence, some critical items must be considered. Investigators must ensure that the search procedure does not go against the law. Computer security specialists need to be granted the required authorization before they can begin gathering potential evidence. Authentication refers to convincing the court that the record content is unchanged, the information present in the record originates from its alleged source, and that the extraneous information, for example the record's apparent date, is precise. As with the paper record, the authentication degree may be proved by circumstantial and oral evidence or by the system's technological features (ENFSI, 2009; National, 2003).

With the rapid technological advancement of recent decades, the amount of digital evidence that law enforcement, lawyers, and investigators encounter has significantly increased. In the absence of digital evidence in this age of technology, the criminals, law breaking offenders, and terrorists would use the technology to commit cybercrimes and evade apprehension, due to the lack of evidence; thus, criminals will go unpunished. The digital evidence acts as the truth teller in the court; thus, it can prove the innocence or guilt of an individual in a crime. Besides, digital evidence can unveil bigger crime plots, such as drug dealing, murder, and even planned terrorist attacks. Therefore, digital evidence collected from the scene of the crime is the key to identifying the suspects and solving the case. Nevertheless, law enforcement and investigators must ensure that the digital evidence collection process follows the key cyber forensic principles to ensure accuracy and credibility (ENFSI, 2009).

Digital Forensic Tools

Forensics experts investigate digital sources through digital forensic analysis. These sources can be mobile devices, PDA devices, tablets, operating systems, and mobile memory devices. The experts use digital forensic tools to analyze and acquire further data from the collected digital sources. Most cybercrime investigations involve digital forensic techniques, and forensics specialists can analyze the level of the crime using high-end forensic tools (Bennett, 2002). The type of digital forensic tool to be used is dependent on the nature of the crime. Also, the efficiency depends on the contribution level toward every level of digital forensic investigation as well as analysis. Some of the common digital forensic tools include Encase (Widup, 2014), Forensics Tool Kit, Helix, CAINE, SANS Investigative Forensics Toolkit, the Corner's toolkit, FTK Imager, Volatility, Free Hex Editor Neo, Bulk Extractor, DEFT, Xplico, Mandiant RedLine, HxD, and the Sleuth Kit (Schweitzer, 2003).

Encase Digital Forensic Tool

The Encase digital forensic tool is a widely used digital forensic tool, as it is used in each step in the process of acquiring the digital forensic evidence, investigation, and analysis. The tool has many features as well as built-in subtools for digital data acquisition. The advanced search option (Encase V7) is used for investigating and analyzing traditional computers as well as digital sources and preparing individual reports (Amari, 2009). The latest version of the Encase digital forensic tool supports the easy accomplishment of query processing and Multiple Language Indexing (MLI) during the process of extracting evidence from the digital source. It provides a binary duplicate, where it provides the digital forensic expert with the option of previewing the evidence information during the evidence source acquisition process. It also does programming language customization, where the object-oriented programming languages, for example C++ and Java, can be used. Finally, different from other digital forensic tools, Encase offers a simple reporting architecture (Amari, 2009).

Forensic Toolkit (FTK)

Forensic Toolkit scans the memory cards and hard disks as sources of potential digital evidence, and can retrieve information that the user has already removed, such as emails, passwords, and relevant text strings. The image tools in FTK are responsible for scanning and retrieving images from the hard disk in the form of either multiple or single disk images. With the Forensics Toolkit, complex MD5 calculations are possible (Ellick, 2001). Forensics Toolkit is the most commonly used digital forensic tool. The main advantages of FTK include reading of multiple sources of digital evidence related files, which include computers, PDAs, smartphones, mobiles, and tablets. FTK is capable of searching, processing, and recovering data packets from the IPV4 and IPV6 protocols. Unlike other digital forensic tools such as NFTS or FAT, FTK can read different file formats. By using the tool, analysts can achieve efficient network, memory, and file management with the user interface and customization simplicity. Another significant benefit is the fast and easy recovery of ARP Ethernet frames. Besides, one can achieve integrity in digital source evidence data against hash value calculations and sophisticated encryption using FTK (Ellick, 2001).

Helix Digital Forensic Tool

The Helix digital forensic tool is a pure UNIX operating system that builds upon the operating system architecture of Ubuntu. The primary purpose of Helix is to digitally obtain, investigate, analyze, and generate reports adhering to the digital forensic requirements. Helix runs over portable memory devices, including the live CD, and can operate across multiple operating systems, which includes Linux, Windows, and Solaris (Cheong, 2008). The benefits of using Helix include the power to run the program and the ability to capture evidence and analyze it while the OS is inactive. Helix can gather full network information and perform a live forensic investigation (Cheong, 2008).

Volatile Memory

As Amari (2009) noted, volatile memory is a computer memory that requires power in order to maintain the information stored in it. Volatile memory retains its content while the power is on, but loses stored data immediately in the case of power interruption. Volatile memory is the main memory in computers. It is not only faster than other mass storage forms, such as the hard disk, but it can also protect sensitive information, since the data is unavailable once the power is down. Random access memory is a type of volatile memory. Non-volatile memory is a computer memory that can retain information even after the power has been turned off. Hard disk, flash memory, and ferroelectric RAM are examples of non-volatile memory. Generally, individuals use non-volatile memory as secondary storage. People use volatile memory to temporarily retain data, thus rendering it appropriate for storing sensitive information, while others use non-volatile memory to store data for an extended period, hence its unsuitability for storing sensitive data. Despite the volatile memory not being able to store information, forensics experts use volatile memory forensic tools to retrieve data from the volatile memory (Amari, 2009).

Data in Volatile Memory

There is a lot of information that is available in volatile memory. Information on registry handles and open files, processes, network information, cryptographic keys and passwords, unencrypted content that is encrypted on the disk, rootkits and worms written to run exclusively in the memory, and hidden data (Amari, 2009). There are several processes running in volatile memory. All of the running processes are stored in the memory and analysts can recover them from the data structures. Terminated processes might still reside in the memory if the user has not rebooted the machine since the termination of the process and the memory space that they used has not been reallocated (Amari, 2009).

Registry handles and open files are stored in the memory. Information on the files which a process is using is paramount. If the process is malware, the open files might inform the investigator of the location of the malware on the disk where the malware is writing its output and the clean files that the malware might already have modified (Yulong, 2015). In the Unix context, the inode structure describes the files that are mapped to the memory and stores information on the memory-mapped files, for example the dates of access, modification, and information on the directory from which the file was executed (if it is executable). Network information, such as established connections, listening ports, and the remote and local information connected with such connections, can be retrieved from memory (Yulong, 2015). Recovery of such information is useful, since malicious users can manipulate the tools on the machine, such as netstat, to send misleading information back to the specialist. Pulling the data directly from the memory dump makes it difficult for perpetrators to hide their connection or listening ports to their home servers from where they are transferring malware.

There is the potential of recovering passwords that the analyst can use to decrypt access user accounts and files of interest. Cryptographic keys and passwords are never stored on the hard disk without protection (Amari, 2009). However, when they are being used, they are stored in volatile memory and will remain there until other data or rebooting of the machine overwrites them. Forensics experts can parse through volatile memory looking for keys and passwords that may assist them in recovering significant data that is encrypted or password protected. The recovery of passwords may help analysts to access online accounts of suspects (Yulong, 2015). When the suspect accesses an encrypted file, the content of that file is unencrypted and loaded into memory (Amari, 2009). The unencrypted content remains in memory even after the user has closed the file. Parsing through the volatile memory may reveal file fragments. Hidden data are also available in volatile memory. Most people hide their sensitive information in volatile memory, since it is safer than storing it on the hard disk. Attackers can run malicious code from the memory, which makes it more difficult for reverse engineering and acquiring program copies and finding more information about the attacker.

Volatile Memory Forensic Tools

Checking the volatile memory for codes and hidden files can result in discovering critical information. Volatile memory forensic tools are used in the acquisition of information from the volatile memory. FATKit is the most common volatile memory forensic tool investigators use, because it automates the data-extraction process from the volatile memory. Once the extraction of data is complete, FATKit has the capability of visualizing the objects it has uncovered in order to assist the analyst in comprehending the information (Amari, 2009). FATKit can analyze structures unique to Windows and Linux kernels. Since the FATKit tool is modular, the analyst can easily extend it for different file or operating systems, and it is scriptable, which allows specialist to develop their own custom extraction techniques. FATKit uses various techniques to provide valuable results to the analyst. It has the capability of reconstructing the virtual address spaces that the processes use, and translating between physical and virtual addresses to create a precise picture of the location of memory when the system was running. FATKit detects the malicious codes residing in the volatile memory (Amari, 2009).

Windows Memory Forensics Toolkit (WMFT)

The Window Memory Forensic Toolkit supports the memory image analysis of machines running Windows 2000, 2003, Windows XP, and Linux. For the analyst to use WMFT, they first need to locate the symbols that point to key objects as well as structures in the memory (Cheong, 2008). Once the location of symbols is complete, the volatile memory forensics expert can plug the values into WMFT and split the data structures to recover processes as well as objects that are stored in the memory. Since WMFT utilizes the structures in traversing memory and pulling out significant information, it is susceptible to advanced attacks, where the attacker hides objects and processes by leaving them out of the data structures. One example is the linked lists that the kernel uses in keeping track of such data (Amari, 2009).

The Volatility Framework tools are developed in Python and specifically designed to apply forensic examination on RAM volatile memory. The Volatility framework is open-source software written in Python scripting language. It provides a platform for extracting and analyzing objects from the memory dumps and supports many operating systems, including OSX 10.5, Linux, and Windows (Amari, 2009). The Volatility framework supports a variety of commands that include commands listing open network connections, a printout of the memory map related to the memory dump under analysis, a printout of an open DLL files list, and a printout of an open files list related to a process. It has the capability of reconstructing and writing out an executable sample from the associated process. The Volatility framework is easy to install as well as run by unpacking it into a system that has Python installed and executing the directive Python volatility.

Encase Enterprise is the widely used volatile memory forensic tool. It has a snapshot utility that captures the volatile information from RAM on certain system types and splits the data to organize it so that it becomes meaningful to the expert. The analyst relies on the software for an accurate interpretation of the memory (Cheong, 2008). Another powerful, volatile memory forensic tool is the HBGary Responder, which performs memory analysis and can reverse engineer malware that is pulled out of the memory. The capability of malware analysis is of interest; it enables the extraction, disassembling, and scanning of suspicious executables uncovered in the memory for functionality and suspect code.

Volatile Memory Acquisition

For analysts to obtain and inspect volatile memory, they need to employ appropriately accredited techniques for acquiring the memory. Volatile memory acquisition methods can either include software-based acquisition or hardware-based acquisition. Amari (2009) argued that using hardware-based acquisition is more effective than using software-based acquisition, since it is more reliable and more difficult to corrupt. However, most volatile memory forensics experts use the software-based acquisition method, as it is cost-effective and easier to access. The volatile memory hardware-based acquisition method suspends the computer's processor and utilizes direct memory access to acquire a copy of the memory. Hardware-based acquisition is reliable, since analysts will still obtain a precise memory image even if the attacker has corrupted or compromised the software on the system or the operating system itself.

The Tribble card is specialized hardware for acquiring volatile memory that allows analysts to capture the memory more reliably and accurately than software-based techniques (Amari 2009; Yulong, 2015). The Tribble card is a PCI card that requires installation on a system before it becomes compromised. Software-based acquisition of volatile memory is performed by using a toolkit provide by the investigator. However, it is also feasible for gathering volatile memory using the built-in operating system tools, such as the dd or mem dump on Unix systems (Yulong, 2015). The technique is susceptible to attackers, since it is easy for them to evade this method by hiding the relevant information through the modification of system calls or internal network structures. On the other hand, this method of capturing the memory may alter some memory contents, potentially overwriting valuable information.

On Windows systems, every object that the kernel uses has an OBJECT-HEADER (Amari, 2009); the structure that contains data on the object stored in it. The kernel has a paged pool and a non-paged pool. The paged pool stores most of the data, while the non-paged pool stores frequently accessed objects. Thread objects and processes are often accessed and stored in the non-paged pool, thus making the processes the physical memory that were running at the time of capturing available to the examiner. In the Linux kernel, it is the mem-map-array that handles volatile memory. It holds all of the page descriptors. The operating system partitions the memory to enable access to the kernel. The mem-map-array structure is used to locate objects as files and processes.

After the volatile memory image is obtained from the computer under investigation, the analyst performs a search to identify anything recognizable in the image. The examiner can use XORSearch to execute the search across the volatile memory image for any data, which can lead to the recovery of critical obfuscated information. In the Linux system, a memory map may be used to identify relevant locations. In Windows, locating objects in memory is a complex task that requires the analyst to have a detailed knowledge of Windows internals across different versions (Amari, 2009). Investigators examine the processes that were running during the volatile memory capture. On Linux, the process descriptor stores the information on the contemporary state of each running process. The structure is called task-struct, and it represents all process types from those that the user invoked to the kernel thread. On Windows, there is a structure that holds all of the information related to the processes. The double-linked list of the structures keeps track of the running processes in memory.

For recovering memory-mapped files in Windows, the investigator starts with the VAD tree's root. The VAD tree is a set of structures that describes the memory range of the processes. The analyst recovers the memory-mapped files connected with each process by going through the VAD tree and extracting the files. Even deleted files can be reconstructed and recovered. The memory-mapped files in Linux are the inode structures. With the inode structure, it is possible to acquire information on the directory from which the user extracted the file and determine the MAC time on that file. To locate the memory-mapped files, the investigator enumerates the processes and then looks at the file structures connected with that processes. The VAD tools are used in recovering the memory-mapped files from the memory dump (Yulong, 2015).

Detection and recovery of hidden data is crucial in volatile memory acquisition (Cheong, 2008). It is recommended to establish techniques to recover objects, in this case files, since the attacker might have terminated processes or closed files before the analyst arrived at the scene. In some cases, the attacker may utilize direct kernel object manipulation to remove processes or files from the tables or lists that the kernel uses to monitor the resources, thus effectively hiding the target files from the Windows API. All objects, including files and processes, have patterns. The header of each process file contains some constants that are the same for the process in the memory. The investigator needs to walk through the entire volatile memory image and look for these constants in order to identify the processes that are not in the doubly linked list that is used to reference the processes, then utilize that as a guide in pointing out the process files that would be missed. Automation of tools has simplified the search for common processes and files.

In Windows, the EPROCESS structure represents the processes that make up the structures and values that describe information essential to the running processes. DirectoryTableBase points to the start of the pertinent structures, and the analyst can use it to go through the information to locate relevant pieces when checking against the conventional process signature that the examiner has mapped out to assist in revealing the hidden processes. The value of PageDirectoryTable is the first check. Each process needs one thread. The ThreadListHead.Blink and ThreadListHead.Flink are the two pointers that the analyst must check to ensure that they point to the address that is greater than 0x7ffffff (Amari, 2009).Both pointers should be pointing to the kernel space where the structure is stored. Following these rules, it is likely to locate the hidden processes in the volatile memory.

Android Forensics

The acquisition and analysis of data that individuals store in mobile phones is gaining significance, as the usage of mobile phones increases. The information investigators can obtain from mobile phones is especially useful in criminal investigations. Due to the rise in smartphone ownership in recent years, mobile internet usage and the number of app downloads has been rapidly increasing (Sylve, Case, Marziale, & Richard, 2012). The information stored on mobile phones, for example videos, images, communication patterns, and recordings, can be used as valuable evidence in criminal investigations. The use of android-OS mobile phones is on the rise; thus, Android forensics has gained attention in law enforcement. Tools including the Android Debug Bridge (ADB), Dalvik Debugging Monitor Server (DDMS), and FMEM, are available for Android forensics. Linux Memory Extraction (LiME) is commonly used (Sylve et al., 2012). In the field of mobile forensics, the amount of data loss once the device is shut down indicates the need for live forensics. According to Adelstein (2006), the IP address, open ports, and a list of running processes cannot be obtained without the help of live forensics.

Legal and Technical Challenges in Volatile Memory Acquisition

The general admissibility of live forensic evidence in courts is still sporadic, due to quality issues of blurriness and taint (Ellick, 2001). Despite the fact that some courts have begun to recognize the value of volatile memory content, the validity of evidence obtained through live forensic analysis is still questionable. A recent guide that the Department of Justice released on evidence collection in criminal investigations suggests that no restriction should be placed on forensic techniques that might be used in the search. It goes on to state that forensic software usage, sophisticated or not, does not go against the requirements of the institution. This guide motivates volatile memory forensics experts to collect volatile information. However, the lack of legal validity in courts demoralizes volatile memory evidence collection (Lillis, Becker, O'Sullivan, & Scanlon, 2016).

Live forensics has its own advantages and disadvantages. According to Hay et al. (2009), the main concern is the system state, meaning that when there is a forensics practice, then most likely the system state will change, especially in the case of mobile devices. Another disadvantage in live forensics is the integrity of the data; for instance, when running a RAM memory acquisition tool, the process table will be updated during the extraction process (Hay, Bishop, and Nance, 2009). Models were designed to improve forensic investigation and satisfy the need for standardization in the forensics field. The model introduced by Rogers et al. (2006) has been approved and has helped to solve many cases. The idea behind the model is to perform an onsite forensic investigation with respect to the time and the type of the case. Some cases require an immediate action to be taken, because it could mean the difference between life and death. Live forensics is included in the model.

A challenge that naturally arises from the ever-rising volume of data, and from the absence of standard techniques in examining and analyzing the increasing types and numbers of digital sources, is diversity, which brings the operating systems and file formats plurality (Lillis et al., 2016). The absence of standardization for storing the digital evidence and formatting the associated metadata also adds to the complexity of sharing digital evidence between the international and national law enforcement agencies. Investigating trans-boundary cybercrimes is also made more complex by the different jurisdictions. For example, it is hard to investigate a suspect in one country who committed a crime against another person in another country, due to legal restrictions (Ellick, 2001.

The complexity problem results from data coming from several different digital sources with varying formats. IoT and mobile devices use various operating systems, communication standards, and file formats, adding to the complexity of the digital investigation. Besides, the embedded storage might not be easy to remove from the device, or the device may lack the permanent storage entirely, requiring expensive RAM forensics. Digital technology is changing rapidly, thus adding to the complexity issue, since investigators find it difficult to apply the available tools in evidence acquisition and analysis (Lillis et al., 2016).

Correlation and consistency issues are arising from the parallel investigation of multiple devices and the logical and temporal consistency of the collected evidence needs to be established (Lillis et al., 2016). The need for RAM forensics also becomes evident in anti-forensics, where a perpetrator takes measures to avoid the acquisition of the evidence, including malware creation, which resides in RAM. The increasing sophistication of digital criminal activities is becoming a substantial challenge. The correlation and consistency issue also arises from the fact that the existing volatile memory tools are designed to locate fragments of the evidence instead of the whole, and the absence of adequate automation for analysis (Ellick, 2001).

Another legal challenge occurs when tools from two seemingly opposing sides have to be used in the same case. The Common Law Models, as described by Brown, gives the two major law enforcement institutions (the police and the court) contrasting roles (Brown, 2015). While the police are tasked with the responsibility of investigating a criminal act, the court performs the duty of ensuring that the rights of the suspects are not undermined and that the evidence presented before it are admissible—there are instances, however, where the defense counsel can gather evidence independently (Brown, 2015). According to Brown (2015), the problem sets in when it is the court that has the final say on whether the evidence presented warrants prosecution or not.

Conclusions

Advancements in technology need to accompany changes in the 3D video game industry; therefore, the graphic computing capacity of existing hardware needs to be improved. GPUs allow the transmission of media and images to operate a separate system, where the flow of information is more efficient when compared to the CPU. The GPU allows the computer to perform the parallel algebraic computations better, since the graphics are handled separately. 3D visualizations of images, videos, and games are among the processes handled by the GPU. The reprogramming capacity of GPUs allows users to optimize the performance of a computer by adjusting its resources. There are inherent vulnerabilities and security issues in GPU-based computing. This is not a surprise, given that GPU was originally designed for graphic processing rather than secure computing. The security risks to GPUs include denial-of-service attacks, leakage of information, jellyfish malware, and the use of GPUs in aiding CPU-resident malware. In this study, the authors challenged the notion that using GPUs as co-processors with distinct memory spaces, less support for many user programming, and limited input-output capability automatically guarantees security, thereby showing that multiple security issues exist in GPU computing software.

As this study has shown, a thorough and legal process of memory acquisition in forensics is needed. Researchers in this field have debated forensics widely, but more areas in the discipline need to be covered. Researchers need to consider systems that run on non-x86 platforms, such as the PowerPC and the 64-bit operating systems. Additionally, systems that exceed a system's 896MB limit should be considered. Creating a generic kernel module that can be loaded using any device, excluding the cross-compilation procedure, solves numerous legal issues used in live forensics. As GPU computing is seeing wider adoptions in fields other than graphics and videos, such as machine learning and cryptocurrency mining, it is vital for the research community to address the security risks associated with GPUs. In addition, tools and technologies need to be developed to provide forensically sound digital evidences of GPU computing. Finally, at the policy and regulatory level, there is a growing need to include GPU forensics as a key element of digital evidence.

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EVALUATING THE ENVIRONMENTAL IMPACT OF WIND POWER GENERATION DURING THE PLANNING PHASE OF FACILITIES PROJECTS

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Abstract

Due to the increase in energy demand and environmental concerns, the quest for renewable sources of energy such as hydro and wind generation has become paramount among government agencies and private entrepreneurs. Hydroelectric power generation is a mature technology; however, it is dependent upon heavy investments, hydrology conditions and (in most cases) extended areas to be flooded for the water reservoirs. In view of these constraints, during the last two decades, governments established concession policies towards wind power. Thus, technology and markets for wind turbines and generators developed at a very fast pace; at first in Europe and the U.S., and then countries like Brazil, China, and Turkey developed their wind power sectors. Although wind farms are exempt from pollutant emissions, their operation and installation promote local physical changes affecting the environment to a considerable extent. In this paper, the author propose a methodology for evaluating the environmental impact of wind power generation as part of an implementation project.

Introduction

Although the use of wind energy goes back to ancient times and has been used for more than 3000 years in processes that require a source of mechanical energy (Noetzold, 2017), its use in electricity generation has a much more recent history, comprising the last 120 years (Leung & Yang, 2012; de Aquino, 2014). With the oil crisis of the 1970s and the discussion associated with global warming, this renewable energy was established as an alternative to the energy demand associated with the evolution of the globalized economy (Noetzold, 2017; Leung & Yang, 2012). Thus, starting in the 80s, large investments were made in wind energy and, as a result, the generation of electricity by wind increased from 2.4 GW in 1990 to 539 GW in 2017 (Leung & Yang, 2012), supplying 5% of the world's electricity demand (WWEA, 2018). It is estimated that by 2030 approximately 27% of energy consumption in Europe alone will be from renewable sources, mostly from wind power (Newell, 2018). Although wind power has performed well and the accumulated experience has been mostly positive, it also creates a significant environmental impact (Siddiqui & Dincer, 2017), which should not be overlooked. The environmental impacts from the installation and operation of wind farms has become an issue that has received considerable attention (dos Santos, 2016; Council, 2007) and, therefore, an environmental impact assessment of the project should be included (Melo, 2016) in the basic engineering design. Since these plants are mostly onshore (Leung & Yang, 2012), the focus of this study was mainly onshore installations; the terms "wind power generation facilities" and "wind farms" are used interchangeably.

Environmental Impact of Wind Farms

The installation and operation of wind farms affects local climate and geomorphology (Müller, 2015), and creates noise pollution and wildlife damage (Saidur, Rahim, Islam, & Solangi, 2011). Given the irreversibility of the participation of wind energy in the global energy matrix, the understanding of the environmental impacts generated by it must be better understood (dos Santos, 2016; Loureiro, Gorayeb, & Brannstrom, 2017). The following are the most common environmental hazards described in the literature that was reviewed in this study, and for which mitigation studies should be considered when designing an implementation project.

Visual Pollution

Due to the large area occupied by a wind farm, it is impossible to deny the changes in landscape and topology, as a consequence of its implementation. The presence of the turbines creates a negative impact by their proximity to inhabited areas, reinforcing the perception of disturbances in the landscape (Zerrahn, 2017). The visual intrusion caused by the wind generators, the occupation of the land, the presence of access roads and transmission lines negatively impacts the landscape. The role of these impacts in the regional socioeconomic context need to be analyzed, in view of the way the local population accepts this landscape change (Bier, 2016). Because it is a recent technology, there is still no exact way of quantifying the visual pollution caused by wind power plants, mainly due to the subjectivity of the theme. There are authors who suggest a visual simulation of the implementation of the enterprise involving the study of micrositing associated with public audiences with the local population (Noetzold, 2017; Melo, 2016; de Aquino, 2014; Saidur, et al., 2011). A temporal assessment of the landscape change, based on satellite photos, is suggested for the monitoring of visual impacts due to occupation and land use (Müller, 2015).

Noise Pollution and Health

The presence of homes near the wind farms, besides the visual/landscape issues, brings noise pollution with negative impacts on the people. The noise generated by wind generators can cause psychological disturbances in people although, according to studies, this will happen in a small part of the population exposed to noise (Zerrahn, 2017). Wind turbines generate noises that are uncomfortable for people in the proximity in two distinct ways: mechanical noises from gearboxes, generators, and bearings, and aerodynamic noises from moving blades and tower structure (Leung & Yang, 2012; Julian, Jane, & Davis, 2007; Oerlemans, Sijtsma, & Méndez López, 2007). Stress manifests itself in people in the form of headaches, sleep disorders, and hearing loss (Punch, James, & Pabst, 2010).

Knowing the sources of noise, steps can be taken to minimize their effects. The profile design of the blades and their dimensions are determining factors, as the air flow when passing through these causes the aerodynamic noise (Oerlemans, Sijtsma, & Méndez López, 2007; Richard, 2007). With regard to noise of mechanical origin, these can be minimized during the design phase of the moving parts and with the application of internal acoustic insulation in the turbine's nacelle; installing anti-vibration dampers in the generator and reduction gear box can also help (Richard, 2007). Since the air flow through the system generates aerodynamic noise (and consequent mechanical noise), a study was carried out to identify a possible relationship between wind speed and noise level. The correlation was found to be relatively low at a distance of 300m from the wind turbine (Björkman, 2004), this being the minimum recommended distance from a habitation for the installation of a turbine (Ministry of Environment and Climate Change, 2008).

Therefore, it was estimated that noise at distances greater than 350m is equivalent to that of a household refrigerator (Leung & Yang, 2012). No consideration was given for the temporary noises from the installation of the wind farm, such as those from heavy machinery for earthworks and soil compaction, as well as the traffic of trucks for the transport of materials (Loureiro, Gorayeb, & Brannstrom, 2015).

Soil Erosion / Disruption

Erosion can be simply defined as the removal and dispersion of soil particles by means of a mechanical action (Eduardo, Carvalho, Machado, Soares, & Almeida, 2013). Although soil disruption is a natural process of soil alteration and decomposition, effected naturally by the action of the winds and rain (dos Santos, 2016), the installation and presence of wind turbines will accelerate the process of local soil erosion (Barbosa Filho & de Azevedo, 2013; Jaber, 2013). This phenomenon begins during the implementation of the wind farm with the need to remove existing vegetation, earthworks for the construction of the bases of the towers, and the installation of buildings and internal access roads. This process increases soil exposure to weathering (Loureiro, Gorayeb, & Brannstrom, 2015; Henrique, 2017). In order to minimize this environmental impact during the planning phase of a project, the planting of native vegetation species, slope protection, and a drainage system for rainwater should be considered (Noetzold, 2017; dos Santos, 2016). In addition to the environmental issues, erosion control is also necessary to ensure the longevity of wind turbine blades, since the particles removed from the soil by the wind have abrasive action on their surface, reducing their useful life and, consequently, burdening the operation (Dalili, Edrisy, & Carriveau, 2009).

Local Climate Change

The earthwork necessary for the preparation of the infrastructure destined for the installation of the wind farm, causes alterations of the local geomorphology, which may alter the hydrostatic level of the water table. This causes changes in groundwater flow, thereby affecting local water availability (Loureiro, Gorayeb, & Brannstrom, 2015; Barbosa Filho & de Azevedo, 2013; Jaber, 2013). Still related to the water issue, the turbulence of the air at the output of the wind turbine causes the evaporation of the ground water to occur at a higher rate (Leung & Yang, 2012; Baidya Roy, 2011) and the same turbulence is associated with changes in temperatures near wind farms (Biello, 2010; Keith, DeCarolis, Denkenberger, Lenschow, Malyshev, Pacala, & Rasch, 2004). In view of these effects, models and simulations are used to search for solutions to this phenomenon (Baidya Roy, 2011; Porté-Agel et al., 2011[Baidya Roy & Traiteur, 2010).

Animal Death of Local and Migratory Species

The negative impact of wind turbines on wildland species begins when the site is being prepared for the implementation of the wind farm. At that time, native vegetation is removed and the shape of the terrain is altered by heavy machinery (Zerrahn, 2017), which affects the behavior of the animals and causes spatial disorientation. During this phase, terrestrial animals abandon their natural habitats, to return later after the completion of the implementation work. After this implantation period, an interesting aspect to be observed is the noise-induced vulnerability by the turbines, which makes it difficult for small animals to hear the approach of predators (Helldin, Jung, Neumann, Olsson, Skarin, & Widemo, 2012).

A similar situation occurs with birds and bats, but with greater severity because they are within reach of the wind farm structures that invade the air space. This specific condition brings risks of impact with the structures installed and creates a barrier for the passage of birds and bats, which are also affected by air displacement due to the turbulence of the wind turbines (Drewitt & Langston, 2006). In this context, there is an aggravating condition for bats, since the sound frequencies of wind turbines interfere with their orientation in flight (Ahlén, 2003; Kunz, et al., 2007). Although the collision with the wind farm features (structures, turbines, etc.) is the main cause for animal deaths (Saidur et al., 2011; Barbosa Filho & de Azevedo, 2013), another cause of death for birds and bats has been discovered: pulmonary embolism due to the sudden pressure variation that occurs with the air flow during its passage through the wind generator (Baerwald, D'Amours, Klug, & Barclay, 2008).

Although there is a lack of quantitative data on environmental impacts, some metrics on bird and bat mortality are available in the literature. According to research, the mortality of birds and bats is measured in two different ways. One uses the number of annual deaths per turbine. According to a compilation made for the U.S. over the last decade for birds, this indicator varied from 0.63 to 9.33 animals per turbine per year. According to this same criterion, in the case of bats, there was a regional variation of 0.01 to 42.7 deaths per turbine each year (Noetzold, 2017). A second form used is the number of deaths per MW generated each year.

In a 2011 survey using this indicator, the average number of deaths in the U.S. was 3.1 birds/MW/year and 4.6 bats/MW/year. In this context, Saidur et al. reveal a curious fact related to animal deaths: cats killed 6.7 thousand times more birds than wind turbines (2011). One way to reduce the mortality caused by wind turbines is to study the behavior of native and migratory species and to seek solutions that can minimize this environmental impact (Hüppop, Dierschke, Exo, Fredrich, & Hill, 2006).

Methodology Definition

Methodology is defined as "a body of practices, procedures, and rules used by those who work in a discipline or engage in an inquiry; a set of working methods" (Collins, 2014), representing a package comprising practical ideas and proven practices for a given area of activity. Andreas (1983) states that methodology relates to how propositions (plans, scientific arguments) can be justified, their bearing on what happens in practice, and which help to provide elements for the definition of a decision situation.

Meta-Methodology

In this study, the authors developed a methodology structured according to the meta-methodology described by Thomann (1973) as a procedure designed to develop and test a methodology for a specific and definable purpose. The methodology is made up of seven basic steps:

1. Identify the area in which a methodology is needed.
2. Determine the purpose around which a methodology is to be developed.
3. Test the purpose against four criteria: desirability, operationability, practicability, and insufficient existing methodologies.
4. Design the methodology to produce its outline.
5. Operationalize the purpose.
6. Design procedures.
7. Test and revise the purpose and/or procedures as necessary.

It should be noted that steps 6 and 7 can be done simultaneously, as step 7 can help the methodologist identify the gaps, and step 6 provides steps that can be tested by step 7.

Evaluation Methodology Design

The IEDF0 (1993) modeling architecture was selected to model the activities related to this work. An IDEF0 model is an ordered collection of diagrams related in a precise manner to form a coherent model of the subject. Figure 1 shows how an activity represents the simplest "Diagram" form of an activity model is called a "context diagram." A context diagram shows only a single activity, whereas a decomposition diagram shows multiple activities. Figure 2 shows a decomposition diagram used to produce a function model, which is a structured representation of the functions of a system and related information and objects. The subject of the activity model is the systematic evaluation of the environmental impact of wind generation by using inputs that are traceable by the evaluator. Figure 3 shows how the evaluation report (output) captures the related processes.

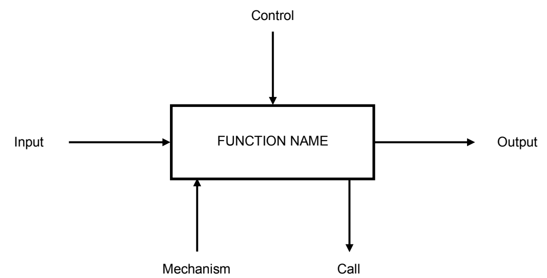

Figure 1. IDEF0 diagram.

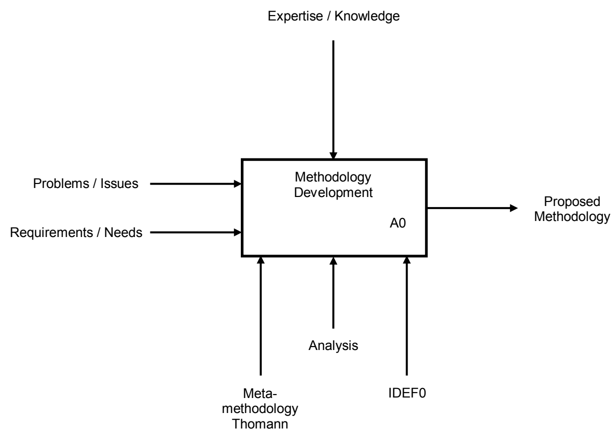

Figure 2. Methodology development - IDEF0.

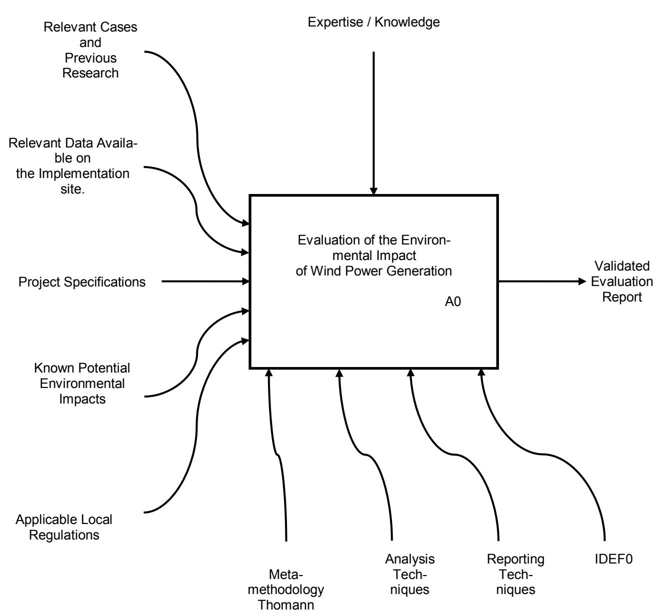

Figure 3. Methodology - node A-0.

The IDEF0 modeling language prescribes that complex activities are broken-up into smaller ones, which can be more readily understood and which will result in a structure that is fashioned after the framework proposed by Thomann (1973). Figure 4 shows how node A-0 is broken down. The evaluation procedure starts with the submission of the project specifications as well as site information, followed by the retrieval of the closest implementation match from a knowledge database. Also, if known metrics on impact from environmental factors exist, they are also retrieved. If enough previous references and/or data are not available, an alternative approach should be attempted, such as the application of fuzzy theory proposed by Enea and Salemi (2001). Table 1 provides a summary of the literature review for this current study and indicates the most significant environmental impacts produced by the operation of wind farms as well as the recommended mitigation measures.

Table 1. Suggested mitigation measures.

Environmental Impact Factor	Mitigation Measures
Visual Pollution	Suggested visual simulation of the implementation of the enterprise involving the study of micrositing associated with public audiences with the local population. A temporal assessment of the landscape change, based on satellite photos, is suggested for the monitoring of visual impacts due to occupation and land use.
Noise pollution and health	In the design phase of the moving parts: Application of internal acoustic insulation in turbine's nacelle; installing anti-vibration dampers in the generator and reduction gear box.
Soil erosion / Disruption	Planting of native vegetation species' slope protection and a drainage system for rainwater.
Local climate change	Models and simulations are used to search for solutions to this phenomenon.
Animal death of local and migratory species	Study of native and migratory species and to seek solutions that can minimize this environmental impact.

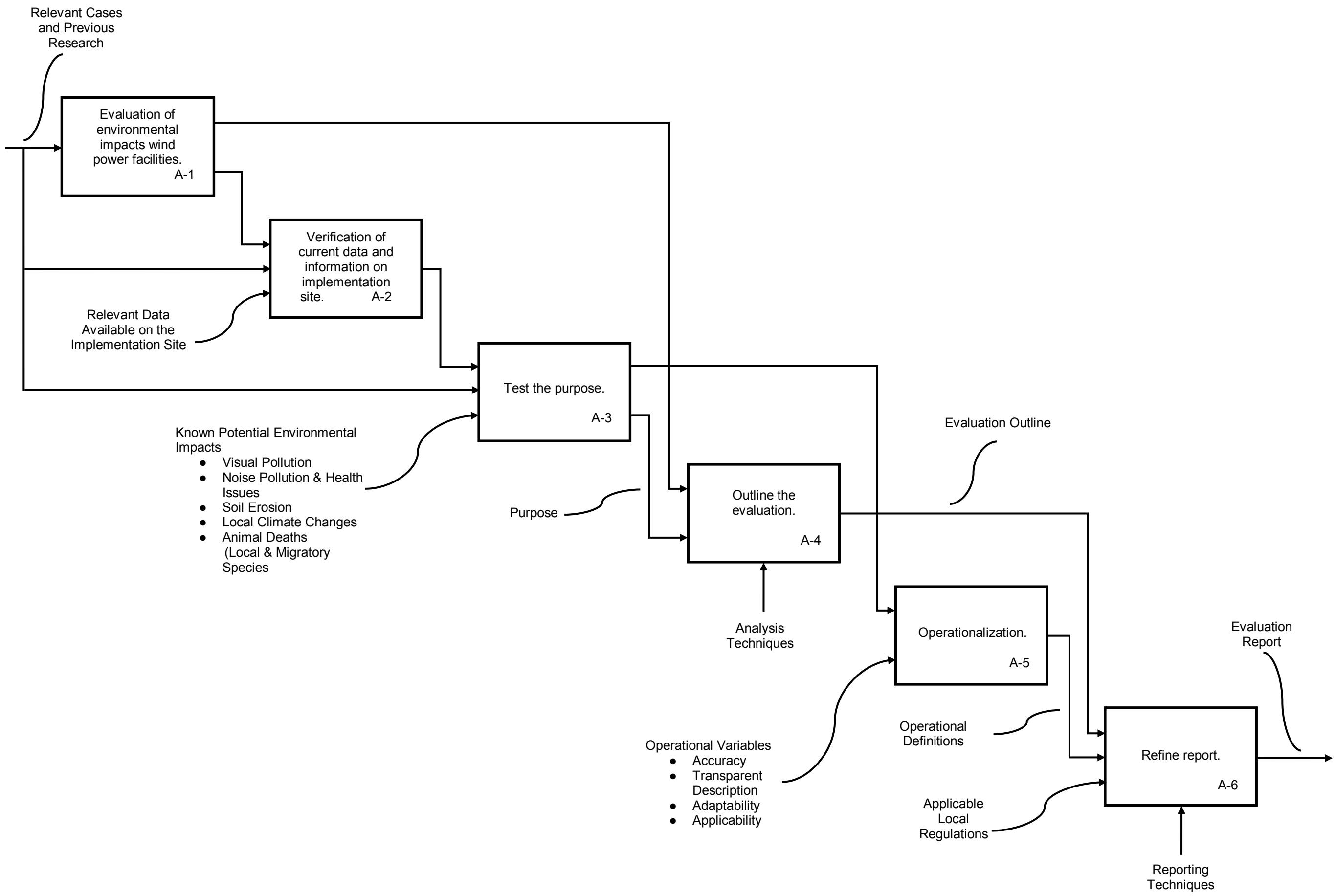

Figure 4. Evaluation methodology design.

The report is then validated in view of local applicable regulations. In node A-3, the requirements from local regulations are appended to the analysis. Although the requirements for the licensing of wind farms vary greatly within different administrative spheres (local, state, federal, international, etc.), in general three types of environmental permits are considered: preliminary license, installation license, and operating license (de Aquino, 2014). The evaluation report is the output of the evaluation process carried out under the proposed methodology. Haffar and Searcy (2018) proposed a context-based environmental reporting framework using an analysis of environmental performance indicators. Others defined this as the "observed value representative of a phenomenon under study" that provides "information about the main characteristics that affect the sustainability of products and processes from a sustainability viewpoint" (Herva, Franco, Carrasco, & Roca, 2011). Figure 5 shows a breakdown of the activities in node A-1.

Node A-1-1 identifies the area in which the required methodology is needed. In this current study, the authors aimed to address the need to evaluate environmental impacts in the implementation of wind power facilities. The availability of relevant data was assessed in order to determine if the evaluation was technically feasible or not (i.e., if the available knowledge is adequate to meet the requirements). In node A-1-2, the purpose was to test for four criteria: desirability, operationability, practicability, and insufficient existing methodologies. Due to the intensity and variety of potential environmental problems caused by wind farms, an accurate dimensioning of their impacts was not being appropriately conveyed by environmental impact studies. For this reason, lawsuits have been filed in different judicial instances and, in some cases, those reports were deemed insufficient to assess possible environmental impacts. Social and political movements have been initiated in opposition to the way that evaluation was done, while environmental experts are recommending a more precise approach in the evaluation process before the installation permit is granted (de Aquino, 2014).

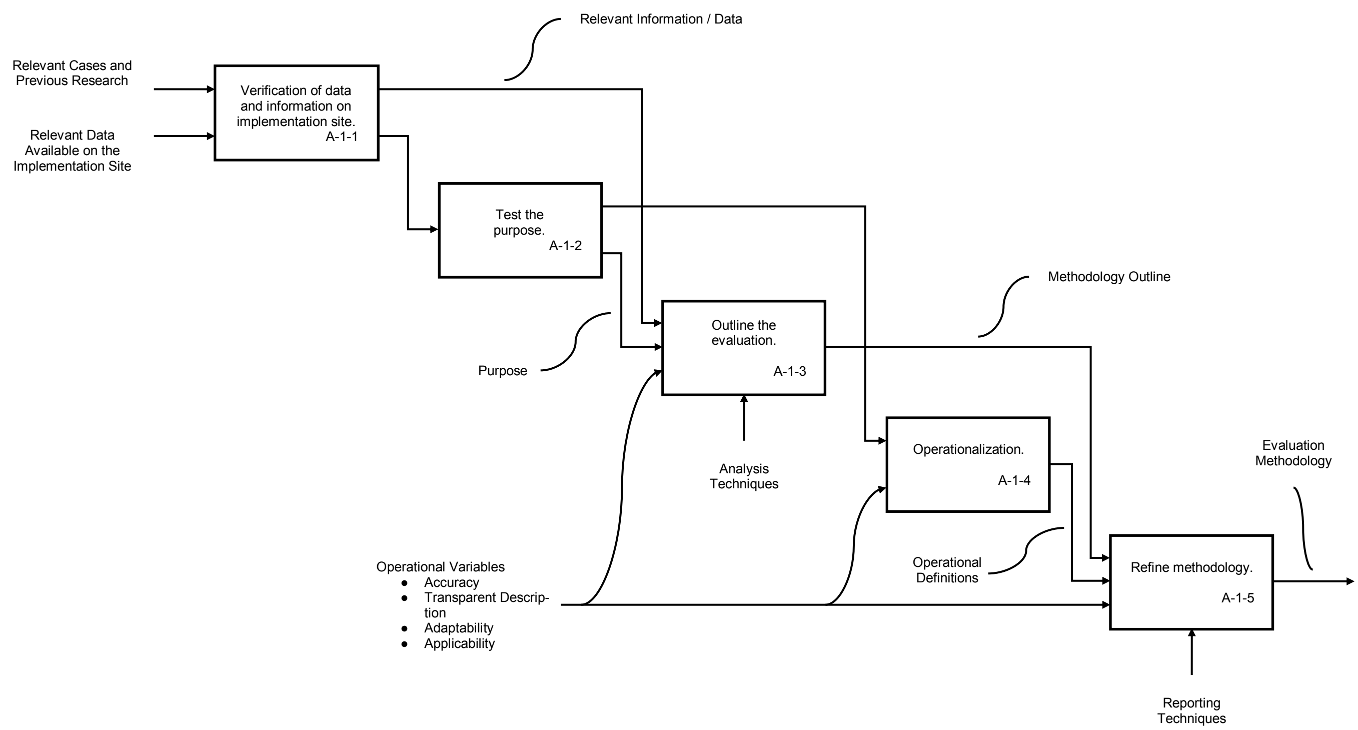

Figure 5. Environmental impact evaluation methodology design – Node A-1.

In node A-1-3, the main problem is further broken down into simpler sub-problems, thereby allowing a more focused approach during development. All available information and data is screened by its relevance and categorized (node A-1-3-1). Processes for site evaluation as well as comparative models and metrics are established (nodes A-1-3-2 and A-1-3-3). A procedure for analysis is then defined and the appropriate tools chosen. These tools are statistical methods, mathematical models, simulation, etc. Figure 6 shows how, at this stage, a preliminary methodology for the environmental impact evaluation is outlined. The environmental impact report is made based on available specifications for the project, site information, and knowledge on possible environmental impact factors (and metrics). As wind power generation is a relatively new power engineering field, all aspects of the technology are not yet extensively understood; the availability of data for analysis and metrics is limited and for this reason the methodology approach is based on the specific case and knowledge of the process. The operationalization of the methodology (node A-1-4) ensures correct answers to the appropriate questions. Table 2 shows a set of operational definitions established considering the methodology requirements.

At this point, taking into consideration the operational definitions set in node A-1-4 of the methodology, the evaluation report is outlined and the environmental impact assessed. In node A-1-5, the methodology is screened for inconsistencies and other possible vices in view of the operational definitions.

Conclusions

The implementation of wind power generation facilities (wind farms) require a comprehensive environmental impact assessment to support the necessary actions and mitigation measures towards minimizing such impacts (Haffar & Searcy, 2018). In this current study, the authors developed a methodology to evaluate the environmental impact of wind power generation during the facility-planning phase of projects, proposed in the form of a structured scheme. The aim of this scheme was to develop environmental impact reports by deploying analytical and reporting techniques, available site information, and knowledge based on previous cases. The proposed methodology will guide the evaluator through the process of creating location-specific documentation. It will also be an aid to agencies (governmental or private) in the bid equalization process, if there is no such procedure already in place. This study is also the first of a series of managerial tools intended to provide a structured approach for the planning of wind power generation projects.

Table 2. Operationalization of the purpose.

Concept	Variable	Operational Definitions
Methodology to Evaluate the Environmental Impact of Wind Power Generation	Accuracy	The methodology provides acceptable accuracy
		The methodology provides good enough accuracy to enable its widespread use
		The methodology provides acceptable accuracy in a reasonable period of time
	Transparent Description of Environmental Impacts	The environmental impacts analyzed using the methodology are depicted in enough details.=
		The methodology exposes the appropriate context
	Adaptability	The methodology allows continuous acquisition of knowledge
		The methodology provides the ability to pass over knowledge that is no longer essential or applicable
		The methodology is transparent to changes in technology and resources availability
	Applicability	The methodology is applicable to the environmental impact analysis in different instances
		The methodology is applicable to complex projects in a practical fashion

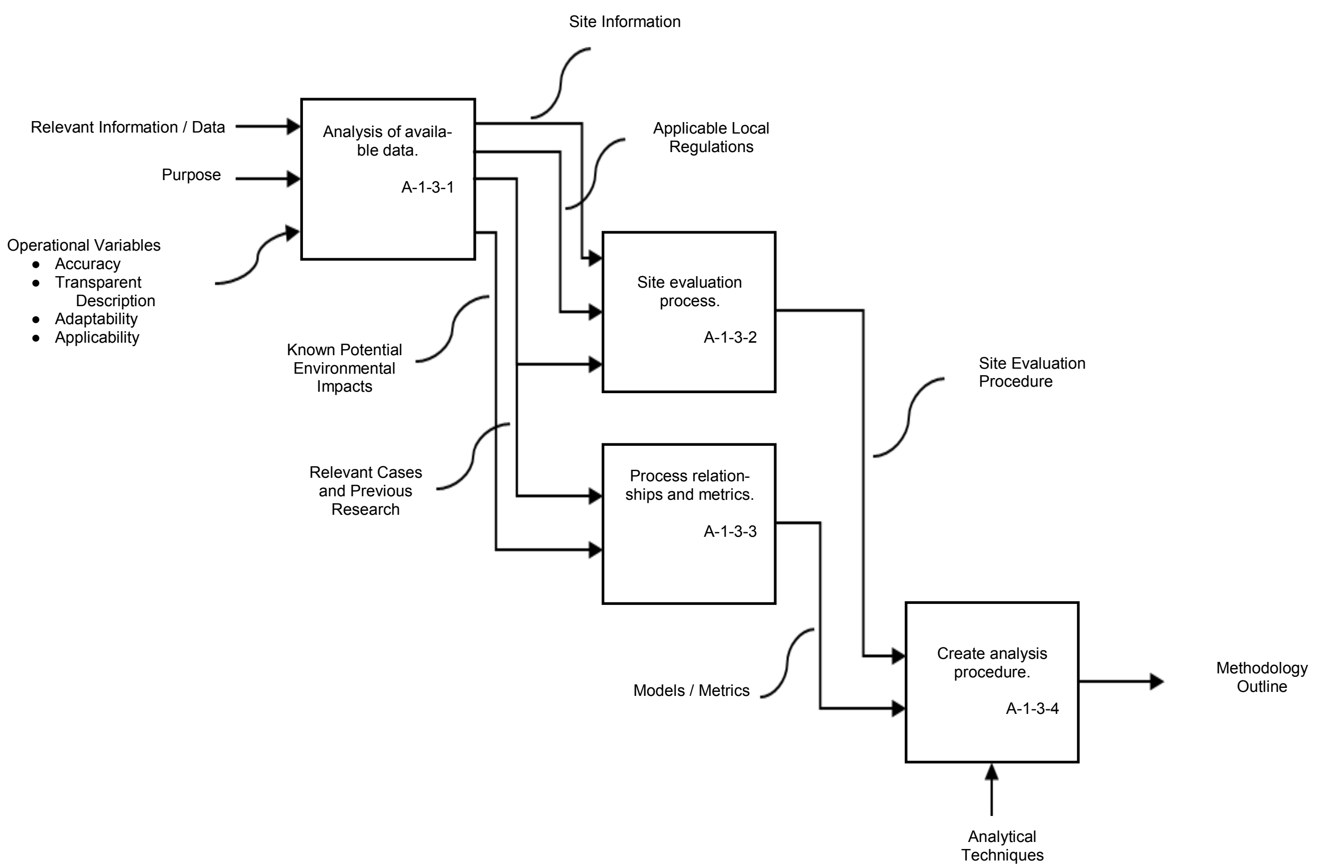

Figure 6. Outlining the methodology – Node A-1-3.

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Development of an Affordable and Portable Eye-Tracking Instrument for Amyotrophic Lateral Sclerosis

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Abstract

The human body is capable of anything from communication to movement, actions necessary for participation in today's society. Sometimes, however, the human body falls into illness that can impair these abilities. ALS, commonly known as Lou Gehrig's disease, is one of many diseases that can alter a person's life by slowly taking away the ability to move and communicate. So far, a cure for this disease has not been found, but many different products have been, and are being created to assist patients in overcoming the hurdles of this disease, thereby allowing them to continue to participate in society. When ALS causes a person's muscular system to stop working, one of the few things left unaffected are their eyes. The research goal here was to utilize an existing sensor and develop software that would allow patients to navigate a basic computer screen using only their eyes. There would also be several functional commands available to the patients simply by hovering over commands icons with their eyes. This proposed system would have potential in the marketplace for furthering accessibility for patients with ALS and other muscular degenerative diseases.

The goal of this ALS eye-tracking system is to replace currently used devices that can be quite expensive, ranging from $5000 to $10,000. These devices also tend to be large and difficult to set up. Using cheaper and smaller eye-tracking devices should address the issues with current devices. The author's goal is to propose a cheaper device with eye-tracking capability, and implement software that would allow its user to control basic PC functions, such as moving the mouse cursor and clicking a few commands. Another goal is to allow the user to have some feedback from the tracking software, such as turning on or off an LED, or playing an audio file from the computer.

History of ALS

The human body is capable of anything from communication to movement, actions necessary for participation in today's society. However, sometimes the human body falls into an illness that can impair these abilities. ALS, commonly known as Lou Gehrig's disease, is one of many diseases that can alter a person's life by slowly taking away the ability to move and communicate. So far a cure for this disease has not been found, but many different products are being created to assist patients in overcoming the hurdles of this disease, thereby allowing them to continue participating in society. When ALS causes a person's muscular system to stop working, one of the few things left unaffected are the person's eyes. Amyotrophic lateral sclerosis (ALS) (Fang, Kamel, Sandler, & Ye, 2008; Vivekananda, Johnston, McKenna-Yasek, Shaw, Leigh, Brown, & Al-Chalabi, 2008; Fallis & Hardiman, 2009; Mackenzie, Rademakers, & Neumann, 2010; Sutedja, van der Schouw, Fischer, Sizoo, Huisman, & Veldink, 2001; Scarmeas, Shih, Stern, Ottoman, & Rowland, 2002; Brooks, Miller, Swash, Munsat, & World Federation of Neurology Research Group on Motor Neuron Diseases, 2000; Shatunov et al., 2010) is a "progressive neurodegenerative disease that affects nerve cells in the brain and the spinal cord" that usually affects people between the ages of 40 and 70. In the 1860s, Jean Martin Charcot, a French neurologist, discovered the disease while studying spinal cords (Vivekananda et al., 2008). The disease originates in the spinal cord, inside one of the lateral regions, home for muscle control and nerve cells.

When a person has ALS, the muscles do not receive any "nourishment," which would usually come via a signal to the nerve cells. Eventually, the muscles start to atrophy until neurons are completely damaged. The loss of neurons in the muscles makes it easier for the brain to lose control of "initiating" muscle movement (Vivekananda et al., 2008). ALS can start with a certain muscle group within the body but will eventually break down all of them. Because of this, affected people may not be able to move their limbs or even hold an object. Patients are usually unable to move, diminishing their overall lifestyle (Fang et al., 2008; Vivekananda et al., 2008; Fallis & Hardiman, 2009). In the late 1870s, scientist Louis Javal first noticed that eye movement was not smooth but rather had many pauses and fixations (Fallis & Hardiman, 2009). He studied people reading books and concluded that the eyes see several visual images combined together at once, which causes them to move in an un-smooth sweep. Nearly a century later, in the 1950s, Alfred Yarbus discovered relationships between fixation and the interest in an object (Fallis & Hardiman, 2009; Sutedja et al., 2001; Scarmeas et al., 2002). His studies, which took many years, concluded that eyes have a predetermined thought process based on objects they have seen before. Eyes basically record what they have seen before that attracts them the most. A person's eyes will tend to first look at something that attracts them, which was recorded by the eye and brain at an earlier time. Eyes will have an order of elements and know how often a person tends to look at them, making the objects pop out to the eyes the next time they see them (Fang et al., 2008; Vivekananda et al., 2008; Fallis & Hardiman, 2009; Norloff, 2017).

In the 1970s, the concept of eye tracking spread worldwide, and scientists were making significant improvements in recording eye movements. More measurements were being accurately obtained and recorded, which allowed scientists to better understand how the eye works. This led to the "strong eye-mind hypothesis" in 1980 (Fallis & Hardiman, 2009). This hypothesis stated that there is no delay time between when the eye sees an object and when the brain processes the information. This was a major finding, since many people did not believe that it could be true. Studies showed that the hypothesis was correct, and there is "no lag between what is fixated and what is processed" (Fang et al., 2008).

In 2001, a Swedish "garage startup," Tobii, was one of the first companies in the world to transform eye-tracking studies into products to market globally (Fallis & Hardiman, 2009). Shortly after its startup, Tobii created the world's first plug-in eye-tracking system that could track eye movement and behavior. The product was used worldwide by scientists to continue studying eyes. By 2005, Tobii once again created the first computer with a built-in eye-tracking camera for the assistive technology market (Tobii, 2018). These products eventually led to the creation of other products, such as eye-tracking glasses and eye-controlled communication devices. Tobii is still the largest eye-tracking technology company in the world today (Tobii, 2018).

Several years ago, the Eyegaze Edge company created the first ALS eye-tracking system to help patients live normal lives while battling their disease (Norloff, 2017). Eyegaze Edge is a system that can help an ALS patient control lights, surf the internet, take classes, play music, and much more. It is simply a computer with an eye tracker built into the screen. A patient moves his or her eyes to complete everyday tasks that they cannot do physically. This allows patients to not feel totally helpless, giving them control over their lives in ways previously impossible. These devices allow for speech synthesis and quick communication shortcuts for phrases. This program is also customizable. This is something similar to the product that the authors of this current study plan to develop.

Current Technologies versus the Proposed System

While researching ALS eye-tracking products, only a few schools that have done a project related to eye tracking were found. An extensive commercial and academic literate review (see References) was completed and it was concluded that there is currently no optimal system for helping ALS patients to communicate. Therefore, in this study, a novel eye-tracking system was developed and tested. The proposed system should be small, portable, easy to use, and affordable. The goal was to develop a successful eye-tracking system for patients with ALS that is user friendly and customizable. It should use open source code and be able to be connected to any PC/laptop computer. The ultimate goal was to create customizable software that can be used by anyone needing help with eye tracking. The plan was to create this project to help ALS patients to communicate easier, while having the option to continue using their own voice. The goal was to see people with ALS continue fitting into society with this technology to assist in communication.

The current operating product in the ALS community has an initial price of $5000 to $10,000. Along with such significant costs, these are large, cumbersome machines that cause discomfort during use. They are heavy, and can cause claustrophobia, because they force users to have their heads in an enclosed space. This is not the only negative effect of these machines, they also require extensive calibration that quickly tires out the user, making these machines less enjoyable and problematic for users. The product developed in this study costs a fraction of the current price, costing less than $200. This new machine is easy to set up and calibrate, using a short 5-minute tutorial. This allows the user to easily use the integrated GUI that performs functions with only the movement of eyes. At first, the proposed eye-tracking system was based around eye-tracker hardware from Tobii. Tobii eye-tracker hardware was bought without its software. The current authors wrote their own code to enable the tracker to work with any computers.

Design Methodology

In order to accomplish mouse movement from the eye tracker, a script was created to slightly move the mouse, and used the Tobii to move the mouse where the user is looking. To generate the GUI interface that should be easy to use, a program using Microsoft Visual Studio was developed to create buttons that would activate when the user/patient looked at it for a predefined period of time, and would play a sound file depending on the button pressed. The developed software can move the mouse cursor on a windows machine based on the reading from the Tobii eye tracker. The Tobii software that the eye-tracking sensor uses does not directly move the mouse cursor to where the user is looking. Instead, the software allows users to move the mouse cursor to where they are looking by either pressing a button or by physically moving the mouse. The users can set up a button on the keyboard so that the mouse cursor will jump to the location of where they are looking when they press that button. Likewise if the mouse is moved even slightly, the cursor will jump to where the user is looking. Neither of these options is suitable for ALS patients, as this would require them to move or press an object physically, which may not be possible. The way to circumvent this issue would be to have the mouse constantly moving on its own so that the cursor will be always jumping to the location the user is looking. As it turns out, using AutoHotKey, a simple script can be written in order to complete this task. This way, no other movement, aside from the eyes, is needed in order to move the mouse cursor on a windows machine.

In Figure 1, the process of eye tracking is explicitly illustrated. First, the eye under consideration should move. Once movement is detected, the eye-tracking software gets initialized. If the initialization fails, the system tries to perform this task until it is successfully performed. Then, the core of the process (eye detection) occurs. Many factors should be considered. The color and the darkness of the eye determine how easy the software can detect the eye. Having glasses also affects the eye-detection process. If the proposed system cannot detect the eye, a message will show up after predefined trials to detect the eye. Once the eye is successfully detected, a calibration should take place followed by an algorithm that would be activated and continuously perform eye tracking until the user/patient unplugs the system.

System Advantages

When it came to testing the proposed system, the eye tracker had no trouble tracking each person's pupils with the mouse going exactly where the user looked. The proposed system is meant to be an affordable and easy to use alternative to the current ALS assistive technologies that are already being used. The devices that exist can cost anywhere from $2000 to $20,000. These products can also be complex, difficult to set up, and tiresome to use by the patient. For patients needing these assistive devices, the costs generally are borne by family members with very little help from insurance companies. These prohibitive costs, then, often mean that some patients will not have access to the best technologies. This is why the proposed system has a chance to compete with these existing systems. Other systems can be difficult and tiresome for the patients to calibrate and set up, leaving them uncomfortable prior to actually communicating. Some of the older machines that are meant to be assistive to ALS patients are bulky and can cause claustrophobia. The proposed system is compact and sits in a laptop on the bedside table. This makes it easier on the patient so that they will not be surrounded by equipment and sitting in a comfortable position while using the Visual Voice system. Most pre-existing programs use standard voice or electrical signals to communicate, while the proposed system can use the patient's own voice, as long as they can record it prior to losing the function of talking. The search team can allow them to integrate phrases that will be directed towards loved ones or towards receiving assistance. This would provide an enjoyable and personalized experience.

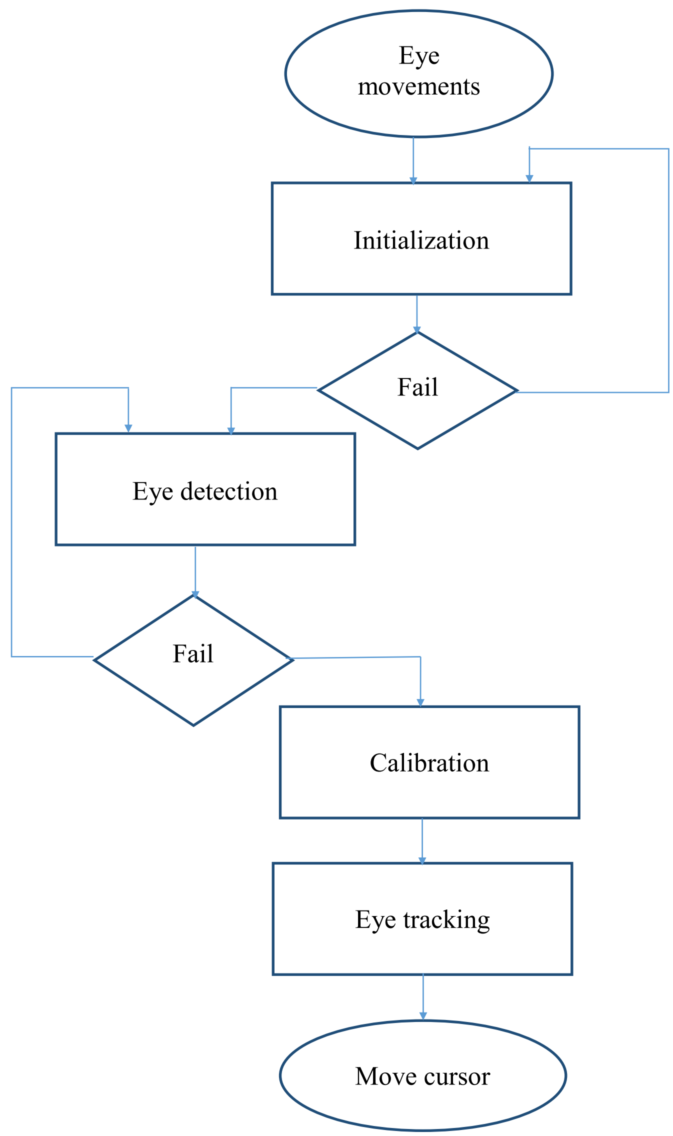

Figure 1. Eye-tracking process.

Risk

The eye tracker uses infrared imaging to detect eye movement, so it is needed to make sure the equipment will be safe. Looking at the user safety manual for the eye tracker, warnings were found about infrared use, as well as some of the standards the device had to comply with. One such standard is IEC/EN 62471:2008, which places devices into risk groups based on how much exposure would be harmful. IEC/EN 62471:2008 includes devices using infrared light. If a device is placed into the low-, medium-, or high-risk groups, it is required to have specific wording in the safety manual. Looking at the Tobii eye-tracker manual, no warnings were found related to the standard; therefore, the device was put into the exempt group. A few risks were found about the eye tracker that are important to keep in mind while using the device. The first is the risk that computer screens and lights pose for people with epilepsy, as they should take care and be sure to stop using the device if it is causing discomfort. The second risk is related to the infrared imaging, as it can cause issues with medical equipment that is sensitive to infrared light. The final warning is related to magnetic fields, as they could interfere with pacemakers if within six inches of one.

Conclusions

ALS, commonly known as Lou Gehrig's disease, is one of many diseases that can alter a person's life by slowly taking away the ability to move and communicate. So far, a cure for this disease has not been found, but many different products have been created to assist patients in overcoming the hurdles of this disease and allowing them to continue participating in society. When ALS causes a person's muscular system to stop working, one of the few things left unaffected are their eyes. The goal of the authors of this current study was to utilize an off-the-shelf sensor and develop a software program that would allow patients to navigate a basic computer screen with only their eyes. Patients would also have access to several commands simply by hovering over them with their eyes. This proposed system will have potential in the marketplace for furthering accessibility for patients with ALS and other muscle degenerative diseases. In the future, this software will be tested by patients suffering from ALS at Charles T. Sitrin Health Care. Depending on the feedback of the study, improvements or changes to the software will be made.

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COMPETENCY-BASED EDUCATION IN ENGINEERING TECHNOLOGY: COURSE DESIGN AND DELIVERY FOR AN ONLINE LEAN MANUFACTURING COURSE

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Abstract

Competency-based education (CBE) has received significant attention in the last several years from the Federal Government, Ohio Department of Higher Education (ODHE), educators, and accreditation bodies. CBE is an innovative approach to improving and enhancing student learning in a STEM program. While the main characteristics of a CBE course and program are generally agreed upon, the final course design is generally unique to individual programs and the institution. In this paper, the author presents the design, development and results of a trial CBE course at Bowling Green State University that could ultimately lead to enhanced student satisfaction.

Additionally, this pilot was intended to validate three aspects of CBE: a) allow students to work at their own pace; b) move through the course by demonstrating competency versus traditional time-bound learning; and, c) utilize the students' industry knowledge of lean manufacturing. There are currently no other programs at BGSU offering CBE-based courses. Successful pilot courses could be the foundation for a full CBE program at BGSU and potentially serve as a model for other engineering technology courses and programs. In this paper, the author: a) highlights the best practices in CBE used at BGSU as they relate to the design and delivery of a course in Lean Manufacturing; b) presents the rationale behind the design and delivery of a trial CBE course; c) establishes the methods for measuring student learning outcomes; and, d) documents the results from the pilot course. Furthermore, the author presents the pilot course results demonstrating that the goals of the CBE pilot were achieved.

Introduction to Competency-Based Education: The Intuitive Philosophy

Competency-based education, or CBE, is being explored and actively pursued by many universities, colleges and even high schools. Recent data presented by McIntyre-Hyte (2016) (citing Fain) suggests that there are approximately 600 universities actively pursuing competency-based programs in an attempt to align academic outcomes with the needs of industry. While there are many factors for pursuing CBE (political, monetary etc.), the main crux for the movement to CBE is recognizing that a shift is needed from the traditional format where coursework is completed on a time-based schedule (i.e., discrete semesters) and credits accumulate towards a degree or certificate. The CBE philosophy is opposite. Students move through a course at their own pace and only move to the next course topic when they have demonstrated mastery of the current topic(s). One cannot move along to the next topic if competency has not been demonstrated. Re-evaluation and further study of the material is required to master the topic and only then can the student move to the next topic in the sequence. The learning model assures mastery of the topic when required competencies are properly identified.

If one examines this CBE learning model, it is quite intuitive and makes sense, especially when paralleled with other activities in society. Sal Khan (2016) founder of Khan Academy, summarizes the philosophy of CBE best as he presents analogies and examples in a TED Talk from September 2016. Kahn describes the process used in the martial arts—one does not move up the ranks in the various belts unless competency is demonstrated. In this setting, this is quite intuitive. Imagine the result if a young yellow belt prospect was allowed to progress into the black belt class/status without fully mastering yellow and green belt competencies. Using Kahn's simple analogy, one can see the implication of CBE in a higher education environment. In STEM courses, fundamental concepts build on each other to form a solid foundation for the next concept. Without mastery of concepts, progressing to the subsequent topic occurs under the traditional, time-based model, but often with consequences. An organic chemistry student may achieve a "C" or 70% on the topic of molecular bonding, but with this level of achievement, 30% competency is not achieved, and the student may not have mastered some key aspects of bonding. When a subsequent topic (e.g., synthesis) requires full knowledge of these competencies as a prerequisite, student performance and mastery of the concept are weakened. However, since the student "passed" the topic at 70%, the student was permitted to move on because, based on the semester format, time and completion of assignments dictates progression. Apply this analogy to the construction industry (building a second story when the first story is 70%

complete) or to the teaching of mathematics or physics. One can clearly identify the potential shortcomings and the need for a new learning model especially in STEM curricula.

Although the historical aspect of CBE is relevant and important, it is not within the scope of this paper. Many other researchers such as Gallagher (2014) and Jones & Olswang (2016) have documented the evolution and history of CBE. This author refers interested readers to these articles for an accurate account of CBE in higher education. There are many definitions and models for CBE. For purposes of this current study, the description of CBE offered by the Competency Based Education Network (referred to as C-BEN) will be the framework for this article. According to C-BEN (www.dbenetwork.org, n.d.), CBE is a flexible way for students to get credit for what they know, build on their knowledge and skills by learning more at their own pace, and earn high-quality degrees, certificates, and other credentials that help them in their lives and careers. CBE focuses on what students must know and be able to do to earn degrees and other credentials. Progress is measured by students demonstrating through valid, reliably assessed learning objectives that they have acquired knowledge and skills required to earn degrees or other credentials in a particular academic discipline or field of study, regardless of the amount of time spent. (https://www.cbenetwork.org/frequently-asked-questions/ in the FAQ section, "What is CBE").

While variation in the approach to CBE exist, the description offered by C-BEN highlights important characteristics that were incorporated into the pilot CBE course at BGSU. These include: a) the opportunity for students to move through the course at their own pace; b) students are able to exploit their knowledge from prior industrial experience; c) there exist various pathways to mastery of concepts and, thus, the completion of the course; d) faculty work closely with students; and, e) delivery is online and targeted at current Ohio learners (75% are 25 years or older and going to school part time (ODHE #1, 2016). The design and delivery of the experimental CBE course offered at BGSU followed these core principles.

The Philosophy and Need for CBE at BGSU

BGSU first encountered the need for CBE when asked to complete a survey from the Ohio Department of Higher Education (ODHE) regarding the institution's intentions for implementing a CBE-based program. In *Competency Based Education, the 9th report on the condition of Higher Education in Ohio* (2016), the state of Ohio's Department of Higher Education (ODHE) published several resources and best practices for Ohio universities and colleges interested in developing CBE programs. This was in reaction to many Ohio colleges and universities that felt that "they did not have enough information about CBE and its potential costs and benefits in order to take the next steps" (ODHE #1, 2016). In this report, the ODHE outlined the rationale for an increased need and interest in CBE programs at its universities and colleges. The executive summary noted that Ohio has a large gap between working-age adults (age 25 – 64) holding post-secondary credentials and the number of working adults needed for current and future Ohio jobs. It is estimated that 43% have postsecondary credentials, but the need to fulfill expected job demand must increase from 43% to 64% of working adults.

Thus, a statewide goal was established: 65% of Ohio working adults will obtain some type of post-secondary "credential of value" (meaning the credential relates to a specific industry or job need) by 2025 (ODHE #2, 2016). Further details are outlined in *The Case for Ohio Attainment Goal 2025* (ODHE #2, 2016). Ohio believes this goal cannot be realized with the current model in higher education, therefore a new paradigm is needed to help achieve the goal. Additionally, CBE seemed particularly well suited to support key strategies identified by ODHE to help achieve the goal: 1) direct alignment of educational credentials to Ohio jobs; 2) increase the number of educated Ohio adults; and, 3) reassess the higher education model, if it promotes positive outcomes for Ohio students.

CBE in an Engineering Technology Quality Systems Program

As a result of the Ohio Attainment Goal 2025" (ODHE #1, 2016) and the increased interest and participation encouragement by the ODHE, BGSU selected the undergraduate Quality Systems degree to pilot a CBE-based course. This degree is offered via BGSU's eCampus where all degrees are delivered 100% online in an eight-week course format. Two (2) eight-week sessions are offered in each traditional 16-week semester. eCampus is an exclusive online degree-granting campus at BGSU where learners can enter a degree program in any of the six sessions offered throughout the academic year. The Bachelor of Technology in Quality Systems is a particularly good fit for CBE and is well aligned with the CBE model. Currently, the quality systems program has an active enrollment of approximately 140 students. The average age for an undergraduate student in the quality systems program is 36 with a range of 22 – 57 years of age. Since this is a degree completion program, each student brings prior college credit and/or an associate degree, and the majority of the students possess industry experience in the quality discipline. Student backgrounds are diverse and include various areas of manufacturing expertise (automotive, aerospace, medical equipment, etc.), service operations, healthcare, education, government, military, food processing, and chemical processing industries.

Students in the program are attentive learners and are generally highly motivated to complete the degree in hopes of promotion, pay increase, or pursuing a better opportunity. For these students, traditional face-to-face instruction is not an option due to work and life constraints. Furthermore, most are employed full time, therefore having the flexibility of schedule and flexibility to complete course activities is essential. The deciding characteristic that makes the quality systems program an ideal fit for CBE is the direct correlation of the course outcomes to the needs of industry, specifically in the field of quality assurance. Courses include Lean Manufacturing, Six Sigma, and the Core Tools of Quality all of which are competencies required by almost any industry that has a quality department or quality initiative.

After examining the characteristics of the students in the program and the fundamentals of a CBE course and/or program, BGSU decided to pilot Lean Manufacturing for Manufacturing and Service Operations course (QS 3550) in the CBE format. This class was selected for three reasons: a) the course represents a current industry need within the immediate BGSU area; b) the course is under the Engineering Technologies, Quality Systems program at BGSU and is a STEM course; and, c) students in the quality systems program are adult learners (non-traditional) with years of industry experience. These reasons support the Ohio Attainment goal. The author, then, a current professor and program coordinator in the quality systems program, was designated as the individual to develop and offer the course in the summer of 2018.

Best Practices from CBE Research and Collaboration with Existing CBE Practitioners

While there is a vast amount of published material regarding all aspects of competency-based education, the author narrowed the search to the *Handbook of research on competency-based education in university settings*. This handbook is a compilation of research surrounding all relevant topics pertaining to competency-based education. Two chapters in particular were utilized while developing this competency-based course. Chapter 7, *The Next Generation CBE Architecture: A learning-Centric Standards-Based Approach* authored by Mott, Williams, Nyland, Atkinson, & Ceglia (2016), and chapter 16, which is a case study entitled *Polk State College's Engineering Technology OEEE Associates Degree* (Byer, Jones, Roe, Bucklew, Ross, & Conliffe, 2016). In addition to the use of these resources, the author is a member of the State of Ohio CBE Network Steering Committee. As a result, some of the theory behind the course design and delivery originated from meetings, collaboration, and discussion with other committee members, most notably conversations with personnel from Sinclair Community College in Dayton, Ohio. Regarding the CBE pilot course design, *The Next Generation CBE Architecture: A learning-Centric Standards-Based Approach* (Mott et al., 2016) outlined a CBE learning infrastructure and a backwards design model developed by Wiggins and McTighe (1998). Many of the concepts were used in development of this pilot course. The CBE learning infrastructure suggested the following pedagogical capabilities:

- Support for backward design at all levels.
- Authentic, effective assessments aligned with course outcomes or competencies.
- Support for learners in a variety of methods/pathways to complete the course and demonstrate competencies.
- Flexibility for course personalization (i.e., self-paced completion, learner prior knowledge, and route-to-course completion.
- Performance measures for the course. (Mott et al., 2016, p. 140).

These capabilities were modified slightly to fit in align with the needs and goals of this current CBE pilot course. In chapter 7 of the handbook (Mott, et al., 2016), a backward approach to design was identified. Phases in this process include:

- Identify the desired result.
- Determine acceptable evidence.
- Plan learning experiences and instruction. (p. 142)

The importance of the backward model in CBE course design cannot be overstated. By defining measurable learning outcomes up front that are then in alignment with the needs of the customer (industry), the student not only obtains the desired competencies but also is provided the opportunity to exploit prior, course-specific knowledge gained from industrial experience. In order to accomplish the desired competencies (outcomes), evidence criteria must be established and assessments carefully designed and varied to assure that these competencies are fulfilled. Lastly, the course design and learning instruction shall allow for attainment of competencies documented with effective assessments. The Polk State case study (Byer, et al., 2016) provided valuable information regarding critical elements of a CBE program. Since BGSU decided to only pilot a course and not yet delve into a full CBE program, elements of a full program had to be considered in the pilot offering.

Items considered from the pilot development that are outlined in the Polk Case study include:

- Course scheduling format—when would the pilot be offered?
- Student registration—how would students be recruited, made aware of and registrar for the pilot course?
- Payment and fees—special fees or same tuition structure?
- Course delivery—100% online, face-to-face, or hybrid?
- Defined student progression—how do students move through the course with flexibility?
- Instructor role—what additional tasks are necessary for the instructor?
- Advising—will advising be available for the pilot offering?
- Consideration of student scenarios—can a student drop from the pilot and return to the traditional course? What is the process for students who fail to demonstrate competency after completing assessments?

Each of the aforementioned elements were presented in the Polk case study along with the corresponding BGSU considerations. Decisions based on these considerations shaped the CBE pilot course. The final piece of research that assisted in development of this CBE pilot course came from collaboration with fellow CBE practitioners at Sinclair Community College (SCC) in Dayton, OH. Items that helped shape this course included examination of SCC CBE course syllabi, discussion with a CBE academic coach/ program coordinator and CBE program project manager, participation as member of the Ohio CBE Steering Committee, and a detailed review of the SSC CBE orientation model and college eLearning website (Sinclair Community College, 2018).

Elements of the CBE Pilot Course

The pilot course consisted of multiple elements. Elements addressed in this paper include the CBE orientation module, student selection, course learning competencies (outcomes), course structure and student progression, assessment methods, grade criteria, and administrative constraints.

CBE Orientation Module

Since most students are not familiar or aware of competency-based education, an orientation module was developed to inform students of the CBE methodology, assess their potential to succeed in a CBE course, communicate course criteria, define the course grading scheme, outline course administrative rules, and define expectations, such as timing and communication. Additionally, a summary of preliminary student questions was posted to a discussion board within the orientation module, which further allowed students to post questions about the CBE course. Both the professor and CBE coordinator monitored the discussion board. Figure 1 shows the main contents within the CBE orientation module.

What is (CBE) Competency Based Education? – Orientation Module

What is (CBE) Competency Based Education?

What is (CBE) Competency Based Education?

Traditional vs. CBE Course Experience – What to Expect

Benefits & Structure of a CBE Course

Purpose of the CBE Piot Course

Quiz: Is CBE a Good Fit for Me?

How to Succeed in Competency Based Education Course(s)

Instructor Role in CBE

Student Role in CBE

Your CBE Coordinator

CBE Course Policies

Course Deadlines and Timing

How Grading Works in CBE

Wrapping Up the Orientation

Statement of Academic Plan

Quiz: Orientation and Grade Policy Quiz

Figure 1. CBE orientation module contents.

Student Selection and Demographics

The pilot offering was planned for the 2018 summer session at BGSU. The course was delivered 100% online using Canvas as the LMS. As previously mentioned, the course chosen for the CBE pilot was QS 3550, Lean Systems for Manufacturing and Service Operations. Since the course is regularly offered in the summer session, the professor and the CBE coordinator examined the list of students registered for the traditional course offering. Correspondence was sent to select students describing the pilot project and their voluntary participation was requested. For those students who expressed interest, each was enrolled in the CBE orientation module. Initially, the professor decided to enroll approximately 5 to 10 students for the pilot course; eight students received correspondence and expressed interest in the pilot course. After completing the orientation module, all of the eight students committed to participation in the pilot course. The pilot course student characteristics are:

- Six (6) of the participating students have industry experience in lean systems and have previously taken online, traditional coursework at BGSU.
- One (1) student possessed industry experience in lean; however, this student had never taken a course at BGSU—this was to be the student's first course since acceptance into the quality systems program.
- One (1) student possessed industry experience, but in an unrelated field. The student was enrolled in the Management and Technology eCampus program at BGSU.
- None of the students had ever taken a CBE course prior to this offering.
- All students were classified as non-traditional or adult learners.

The sampling of students from the population (all registered students for the QS 3550 traditional course offering) was both convenient and purposeful. The majority of students in the program had industry experience, were classified as non-traditional, and all were degree completion students (meaning that they had transferred previous college credit or an associate's degree). A "new to BGSU" student and a student from outside the quality systems program were selected to serve as the control for the pilot offering.

Course Competency—Learning Outcomes

The course learning outcomes were as follows:

CO1. Compare and contrast the benefits and shortcomings of mass production, craftsmanship, and lean manufacturing.

CO2. Apply the principle concepts of lean systems in a manufacturing or service environment.

CO3. Demonstrate how to develop and apply standardized work in lean systems.

CO4. Apply the concepts of stability to lean systems in a manufacturing or service environment.

CO5. Define and apply the principles of JIT, Kanban, and Production Leveling.

CO6. Explain the concept of Jidoka and its importance in lean manufacturing.

CO7. Explain why involvement of people is critical to success in lean systems.

CO8. Define and outline the steps of Hoshin Planning.

Each of the learning outcomes was associated with a discrete learning module dedicated to establishing and demonstrating competency.

Course Structure and Flexible Progression

The CBE course shell consists of eight discrete learning modules, each of which has associated core competencies. These competencies must be fulfilled (demonstrated comprehension) in order to successfully pass the learning module and move to the next module in sequence. The coursework can be done at the students' desired pace; once a module is open, the module does not close until you complete the module by either passing the pre-module competency evaluation with a minimum score of 80% or by passing the post-module competency evaluation with a minimum score of 80%. After successfully completing the 4th module in sequence, a course mid-term competency evaluation must be completed with a minimum score of 80%. This process is then repeated for modules 5-8, culminating with the final course competency evaluation that must be completed with a minimum score of 80%. Figure 2 presents a sample of a module in the pilot course.

Introduction Module: CBE Introduction and Orientation

Link to the CBE Orientation - BGSU
Instructor Self Introduction
Suggestions for CBE Success
CBE Concept Explained –TED Talk Video Sal Kahn
Get to Know Me Discussion

Module 1 The Birth of Lean Manufacturing

Module 1 Pre-Evaluation
Module 1 List of Required Activities
Module 1 Learning Objectives
Module 1 Video
Module 1 Assignment – The Birth of Lean
Discussion with Instructor - Module 1
Student Name – Private Discussion Instructor - Module 1
Module 1 Post Evaluation

Figure 2. Example of a CBE module and contents.

Each learning module contains a pre-module competency evaluation. Completing this evaluation is optional; however, by successfully completing the evaluation, the student demonstrates that he/she already possess the necessary competencies to move to the next module in sequence without the need to complete all of the module learning activities. Thus, if a student takes the pre-module competency evaluation and obtains a minimum score of 80%, the next module in the sequence is automatically available and unlocked, and no further learning activities are required. If the student does not pass the pre-module competency evaluation with a minimum score 80%, the student must complete the module learning activities and then pass the post-module competency evaluation. This process repeats, at the students desired pace, until all eight learning modules are complete and the mid-term competency (after module 4) and final course competency evaluation (after module 8) are completed with a minimum score of 80%. To incorporate social interaction, discussion boards are contained within each module providing two options for student-student and instructor-student interaction. Moore (1998) (cited by Colson & Hirumi) states that student interactions transpire "between one learner and another learner, alone or in group settings, with or without the real-time presence of an instructor." Furthermore, Colson & Hirumi (2016) describe student-student interaction this way: "Learner-learner interactions help groups and individuals construct knowledge and apply targeted skills. Typically, learner-learner interactions ask students to discuss important topics by using online discussion forums to share information opinions, and insights." Standard #5.4 of the Quality Matters Rubric 6th edition (Quality Matters, 2018) requires that "The requirements for learner interaction are clearly stated." Thus, it is a required component of an online and/or CBE-formatted course.

For a specific module, discussion is open for students to post questions, concerns, or general comments and feedback regarding the module's content. Both students and the professor are active in these discussions. Additionally, a private student-instructor discussion exists for each student to privately communicate directly with the instructor. A student may also elect to attempt an accelerated course-completion option. The student has the option to proceed directly (bypass modules 1-4) to the mid-term competency evaluation. By completing the mid-term competency evaluation with a minimum score of 80%, the student may proceed to the final course competency evaluation. However, a score below 80% on the mid-term competency evaluation indicates that the student must begin the course at module 1. Obtaining a minimum score of 80% on the final course competency evaluation indicates course completion. A score below 80% indicates that the student must begin the course at module 5. In this pilot course, a non-traditional syllabus was created. Since all of the course policies, grading criteria, and information are contained in the mandatory orientation module, the syllabus was streamlined to only include course topics and suggested completion timing, essentially a schedule of course content with suggested completion timing. Table 1 shows the syllabus/course schedule used to guide the students in the CBE pilot course.

Defining the Competency Model: Method of Assessment and Grade Criteria

All assessments and learning exercises are graded using a competency scale, where 80% is the minimum score a student must achieve in order to demonstrate mastery of the learning outcome. Schaef (2016) stated, "If you scan the field, you'll notice that mastery means many different things to different folks. Some define mastery as 80%! Some define mastery as Advanced! Others use the term mastery, but have not yet defined it. It is important to be clear, thoughtful, and I would argue, quantitative, when you define mastery. You'll want a consistent set of tools (rubrics, a rating system, scoring rules, and calibration protocols) for measuring it fairly and consistently, too." Therefore, it is important to define the competency model used in this pilot course and to note that 80% mastery differs from obtaining a grade of 70% or 80% in a traditional course offering.

According to Colson & Hirumi (2016), "There is often a misconception that competency implies a very high level of performance such as 90-100%. In fact, competency has a range of scores associated with it just like the term passing. A student may pass a course with a grade range of 60-100%. Likewise, students may be considered competent within a range of scores, usually from about 75%-100%." In this pilot course, students were considered competent when they: a) have completed the module assessment with a score of 80%, and b) have completed the formative essay questions with a score of 80%. Each of the competencies must be demonstrated to advance to the next module. A score of 80% is not arbitrary and represents the level of competency typical of industry certifications offered in lean manufacturing.

Demonstration of mastery was done through learning activities, module evaluations, and module-specific summative essay questions. The student is permitted to have two attempts at any graded learning activity assignments/post module evaluation in the CBE course. However, this does not apply to pre-module evaluations nor does it apply to the mid-course and final course evaluation, if the student elects to skip modules and proceed directly to the mid-course evaluation. If the student does not obtain 80% on any of these evaluations after the 2nd attempt, the professor/instructor is engaged and makes a determination how or if the student will progress to course completion. For each and every assignment, the student must obtain at least 80% to demonstrate mastery of the module and associated competencies. Like many online courses, it is not always feasible to incorporate lab activities. Evaluations focused on application-based (based on an industry scenario) assessments in lieu of a lab activity. While not utilized in this pilot course, future

Table 1. Syllabus for pilot course.

Competency Based Education - QS 3550 Pilot Course					
Module	Topic	Reading Assignment	Start Date	Suggested Completion	Week
CBE Orientation	CBE Guidelines	Module Content	Prior to Course Enrollment	Prior to Course Enrollment	1
Module 1	The Birth of Lean	Chapter 1	May 14, 2018	May 21, 2018	1
Module 2	Lean Production Systems	Chapter 2	May 21, 2018	May 28, 2018	2
Module 3	Stability	Chapter 3	May 28, 2018	June 4, 2018	2
Module 4	Standardized Work	Chapter 4	May 28, 2018	June 4, 2018	3
Mid-Course Competency Evaluation Modules 1-4					
Module 5	Just in Time	Chapter 5	June 4, 2018	June 11, 2018	4
Module 6	Jidoka	Chapter 6	June 4, 2018	June 11, 2018	4
Module 7	Involvement/Culture	Chapters 7 & 9	June 11, 2018	June 18, 2018	5
Module 8	Hoshin Planning	Chapter 8	June 18, 2018	June 22, 2018	6
Final Course Competency Evaluation Modules 1 - 4					

CBE courses will require the use of Respondus to validate student identification. Additionally, Lockdown Browser can be utilized for all module evaluations. Both programs are LTI's available in Canvas. This will help assure the integrity of a CBE program.

Delimitations—Administrative Constraints

Many options can exist in a given CBE program/model. Fees structures may vary from a traditional pay-for-credit model to a subscription-based model. Student flexible pace can be open-ended or course completion may be in line with a traditional semester. A program could be modeled as a direct assessment CBE or as a course-based equivalency CBE model. Therefore, a need to define pilot course delimitations is important for administration. The delimitations of this pilot course were:

- The student must complete the course within the traditional semester timeframe.
- The student may start the course at any time within the semester, but must complete by semester's end.
- Tuition is a traditional, credit-based fee.
- The student may opt out of the pilot within the first two weeks of the session and be placed into the traditional course.
- Students who complete the course early do not have the ability to enroll in another course (as in a subscription-based CBE program) until the next available semester.
- If a student does not finish the course within the traditional semester timing, a grade of incomplete will be entered without requiring rationale from the student. The incomplete is granted outside the traditional university policy for incompletes, which typically allows only incomplete marks if documented extraordinary circumstances exist.

These particular delimitations were chosen for the pilot course. The pilot course would also be used to determine if CBE is a good fit for BGSU; thus, as the CBE program develops, these delimitations may change based on feedback from the pilot course.

Results

Student Grades and Completion Rate

All students completed the entire course within the given semester (6-week summer session), while three students completed the course at the end of the third week of the semester. Table 2 summarizes the grades and completion rates. All students obtained the minimum competency 80% (B) in the course. Table 3 shows a breakdown of each learning outcome (LO) with the number of students achieving competency levels for each LO.

Table 2. Student grades and completion rate.

Student Final Grades	Final Grade	Time (weeks) to Complete Course
Student #1	B	6
Student #2	B	6
Student #3	B	6
Student #4	A	6
Student #5	A	6
Student #6	B	3
Student #7	A	3
Student #8	A	3

Table 3. Learning outcome competencies for the entire class.

% Students Obtaining Level of Competency			
Learning Outcome	Exceeds > 90	Meets >79.9 and < 90	Does Not Meet < 79.9
CO1	38	63	0
CO2	13	88	0
CO3	38	63	0
CO4	50	50	0
CO5	38	63	0
CO6	13	88	0
CO7	13	88	0
CO8	50	50	0

Course Assessment—Student Feedback from Interviews

As students completed the course, qualitative data were collected from a post-course completion interview. The interviews were conducted over the phone by the CBE coordinator at BGSU and the professor. Questions utilized during the interview are listed here in the Appendix. The author notes that each interview was recorded (with the consent of the interviewee) and the dialogue of each interview was transcribed. Table 4 shows the main themes (from coded qualitative data) taken from the interviews as well as provides summaries of each student's experience (eight students in total) in the CBE pilot course. Examining the achievement of learning outcomes, student completion rates, course grades, and the qualitative data gathered from the post course interviews, the main benefits (as expressed in the literature) and goals of this CBE course were obtained. Students achieved the course competencies working in a self-paced atmosphere, while being able to utilize/build upon industry knowledge and experience in lean manufacturing. Thirty seven percent of the class completed the course in less than the allotted semester timing and the remainder of the students, while taking the entire six weeks, expressed the significant benefit of having the flexible course pace and no set schedule of learning activity due dates. Additionally, all students believed that the independent pace was beneficial, when compared to a traditional offering, and all students stated that less time was spent achieving the course outcomes versus the traditional, time-bound course format.

Most students, with the exception of student #1, preferred the CBE format to the traditional course format. Student #1 felt that, in a traditional course format, concepts that are difficult to understand may be better explained or understood if groups (of students) could discuss course material; student #1 further explained that the option (open discussion) was available yet did not take advantage of the discussion area. In brief, the CBE format did not fit the students' preferred learning style; however, student #1 very much supported the flexible-pace aspect. Furthermore, most students believed the rigor of the course, or level of difficulty, was not compromised in this format, and most felt it was equal to the rigor experienced in a traditional course in the same program (quality systems). Several students cited both the text selection and prompt instructor feedback as a significant characteristic that made for a positive experience and helped promote competency-based learning exploiting a flexible pace. Below are a few select student quotes taken from the interviews that are aligned with the data analysis and goals of the pilot course:

Q: What do like about the course?
A: *"There was of course being a non-traditional student with outside responsibilities beyond academia meaning family, work requirements. This setup in terms of the CBE was wonderful. In addition to it being online it allowed me to go at my own pace whether it be expedited or I'd say not slower attached to a rigid schedule, something must be submitted by such and such date, so I found that wonderfully helpful in terms of being able to working it into my work and family schedules. Then the other thing that was a benefit was the number of years of professional experience, specifically in this course, being able to go ahead and take the testing through the modules was a great help also."* – Student #6

Q: How did you feel this style of course accounted for your professional experience?
A: *"Oh yeah, when it came to the book and the specific questions and applications that the modules covered abso-*

Table 4. Student qualitative course assessment.

Theme Designation for Coding	Main Interview Themes	Student #1	Student #2	Student #3	Student #4	Student #5	Student #6	Student #7	Student #8
A	Independent course pace is a benefit compared to traditional approach	A	A	A	A	A	A	A	A
B	Student has taken at least one (1) online course	A	A	A	A	A	A	A	A
C	Student prefers the CBE approach preferred over traditional	D	A	A	A	A	A	A	A
G	Time spent on this CBE pilot is less than time spent on a traditional course	A	A	A	A	A	A	A	A
H	Assessments are true demonstrations of competency	N	A	NA	A	NA	A	A	A
I	This was the first/only CBE format course taken by the student	A	A	A	A	A	A	A	A
J	Student believed industry experience was beneficial and was exploited in this course	A	A	A	A	A	A	A	A
K	BGSU should offer more courses in this format	A	A	A	A	A	A	NA	A
L	Student believes course rigor is equal or above traditional course rigor	A	NA	A	N	A	A	A	A
M	Specific areas of improvement expressed by student	Had particular difficulty with assessments	None	None	Ambiguous wording of some questions	Allow a bit more time for essay questions	Allow a bit more time for essay questions	Some questions seemed tricky	None
N	Other specific positive(s) expressed by student	None	None	Instructor prompt feedback	None	Excellent Text	Feedback from Instructor	Excellent Text to Support Learning	Direct & frequent interaction with instructor

lutely was very indicative of what I experienced in my professional life, absolutely." – Student #6

Q: Are there pros and cons of CBE course format?
A: *"Yeah so I think one of the good things about this class is you didn't waste a lot of unnecessary time going through assignments where you pretty much already knew the material. So I think that was probably the biggest benefit for me was you weren't kind of wasting time relearning that information".* – Student #8

Q: How did you feel this style of course accounted for your professional experience?
A: *"Uh absolutely, it really good for the people who have been in the industry for a while that have gained that basic understanding of the material. I think that's the people who benefit from this the most. So I'd definitely, I'd love to see other classes follow the same suit".* – Student #8

Q: When you did not achieve the minimum competency score, did subsequent assignments help?
A: *"Yeah. Yeah it was like every time I failed a module it was like I was so close; but then after I would study the questions that I had missed the first time and I would just go over the chapter again and do that homework. So by the time I got to that last test then it wasn't difficult."* – Student #2

Q: How did the CBE experience compare with a traditional QS course?
A: *"The class really let me kind of show off what I already had, which was really great." "So…there's value in both. The self-paced really does add a lot of value to the being able to work at my own pace. If I had known that we had the option I might have signed up for another class this semester. As far as a business education you can double your ROI potentially or triple it. To a certain extent I'm actually using a company reimbursed tuition, so a little of an eliminating factor of them trying to not do too much without pay so my company is able to pay it more".* – Student #7

Faculty Role, Workload, and Involvement

Prior to offering the course, the traditional course had to be modified to the CBE format. This included creating competency-based assessments, modifying course curriculum, and building a new course shell in the LMS (Canvas). Overall, the author spent approximately 23 hours within Canvas developing/converting the new CBE format for QS 3550 Lean Manufacturing. Additionally, another 20 hours was dedicated to developing the course assessment outside of the Canvas course shell and then loading the assessment into the course shell. Thus, course conversion required about 53 development hours. Since each student had a dedicated personal discussion board to interact with the instructor, the author responded directly and individually to student questions, concerns, and comments. Ultimately, 59 hours of total instruction time were spent in the class for the 6-week session; the interaction time spent with students in Canvas was approximately 7.4 hours per student or 1.4 hours per day. This did not include answering daily e-mails from students (who were asked to keep all correspondence in Canvas, but some did not), and, on average, replied to seven emails per week outside of Canvas from CBE students. It should be markedly noted that daily correspondence and checking of student progress was required. It is feasible that this daily interaction could be reduced when the CBE format is more mature; however, the attention was needed to ensure that students did not have a negative experience.

Within the 6-week period, there was not any single day during which some student-instructor interaction was not required. Daily interaction and feedback was critical to course success. Comparing this with the standard section of QS 3550 that was run concurrently with the CBE version, the author spent a total of 71 hours and the course contained 43 students, which is approximately 1.6 hours per student. In the traditional course, some of the time spent is outside of Canvas (off-line grading, e-mails, etc.); thus, the 1.7 hours per student may be on the low end of the true value. It should also be noted that the author has taught the traditional QS 3550 course several times. In either case, it is important to note the increased amount of time from a faculty member in a CBE course. Future iterations of the course would probably require less time, due to a decrease in curriculum development and experience with executing a mature CBE format.

Future CBE Considerations and Conclusions

Based on the student experience and results from the course, the CBE pilot course fulfilled its preliminary goals: a) to allow students to work at their own pace; b) to move through the course by demonstrating competency versus traditional time-bound learning; and, c) to utilize the students' industry knowledge in lean manufacturing. The pilot course provided an initial foundation demonstrating that the CBE concept can work well, especially with non-traditional and/or working students. While there are many considerations before launching a full program in a CBE format, this initial step has answered some important questions for CBE at BGSU. Further research and exploration into competency -based education within the Quality Systems program will be ongoing. A second pilot course is planned for QS 3710, Six Sigma, where the sample size of students will be increased and students will be given a choice at registration to choose CBE versus traditional; thus, students will not be selected as in this pilot course. After completion of the second pilot course, pending outcomes, the focus will be on potentially taking the Masters Certificate in Quality systems to a full CBE offering. It is important to note that student demographics (i.e., working students possessing quality-related experience) seem well aligned with the CBE framework, and other programs may not realize the same positive results as for this quality systems pilot course. Furthermore, what this pilot course and paper did not present or consider are other important challenges when implementing CBE, such as faculty buy-in, financial aid, accreditation, program model, (subscription-based or pay-per-credit), and faculty role alteration.

The CBE pilot course was developed from the need identified by the State of Ohio Department of Higher Education. Many of the principles used in the course design and development were drawn from existing research and represent current best practices for a CBE course. It is important to note that many models for CBE course design and development exist; this pilot course offered many best practices and was designed to specifically fit the needs of BGSU Quality System students. The reader is encouraged to explore CBE resources, such as C-BEN the Competency Based Education Network (www.cbenetwork.org), the Journal of Competency Based Education, and the Handbook of Research on Competency Based Education in University Settings.

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Biography

CHRISTOPHER KLUSE is an assistant professor of Engineering Technology & Quality Systems at Bowling Green State University. He is also the quality systems program coordinator. Christopher holds a PhD in technology management with a specialization in quality systems from Eastern Michigan University. Christopher is a former Quality & Manufacturing Professional; the majority of his 25 years' experience was spent in the automotive industry. Additionally, Christopher is an ASQ Certified Manager of Quality/Organizational Excellence and formerly served as a part-time lecturer (while employed in industry) of quality management at Eastern Michigan University and as a subject matter expert in quantitative studies and operations management at Southern New Hampshire University. Dr. Kluse may be reached at ckluse@bgsu.edu

Appendix

Post-course-completion, open-ended interview questions:

1. What did you like about the course?
2. What didn't you like about the course?
3. What could be improved in the course and in the course delivery?
4. How did the course flexibility of pace benefit you?
5. How did the CBE experience compare with a traditional QS course?
6. How did you feel this style of course accounted for your professional experience?
7. Did you feel that the learning activities prepared you for the module assessments?
8. What was your amount of time and energy spent on content before attempting and ultimately passing assessments?
9. If you could complete the traditional course in a self-paced paced format vs. the CBE format, what would you prefer and why?
10. Did you feel that you were able to utilize your industry & life experience to move through the course efficiently?
11. Was the professor interaction and feedback timely and useful?

Note: Other impromptu questions were asked based on the some student responses. All interviews were recorded and transcribed for data analysis.

Suggestions for CBE Pilot Success Posted for Students in the Introduction Module

<u>Suggestions for Success and Course Background</u>

I want to again thank everyone for offering to participate in the pilot course. I truly believe Competency Based Education is a great model especially for working students with experience in the field. This approach to education is gaining popularity, however my interest is from a more personal standpoint. In brief, from my associate degree that I obtained from a community college to my PhD, I was 100% a working student. I would have loved to be given the opportunity to self pace my work and also utilize some of the knowledge I had gained while working in industry. Thus, my hope is that this course can offer both of these aspects; (1) the ability to move through the course at you own pace and (2) exploit the knowledge you already have gained from real life experience. Please watch the video (if you have not already done so) regarding the concept of CBE. It really explains the concept quite well!

<u>Items of Note</u>:

- I am not using a traditional syllabus in this course. The grade policy and all other important items are contained in the CBE orientation module. Refer to this Canvas Course for any questions about CBE course policy. You can always reach out to me using your private discussion or module discussion board.
- You have 2 methods to communicate with the instructor. Each module has a "public" discussion board and each student in the course has a private discussion board. I will monitor these daily as re-

spond generally within about 4 - 6 hours. If I don't answer, send me a reminder or a text message.

- If you DO NOT hit 80% on a given evaluation, please notify me. Since this is the first time I am using these questions and evaluation methods, I want to evaluate each case by case, I don't want you to get discouraged if you score 79% and can't move on. I will evaluate and act. Also when you take a Module Pre Evaluation, keep in mind there are essay questions that are **not auto-graded.** Thus, I need to review and assign the grade to these questions. So do not panic or get discouraged when you finish a pre evaluation and you see a score of say 56% which indicates 14/15 correct on the multiple choice questions and 0/10 for the essay questions. The evaluation grade is not final until I grade the essay questions. I will get this done within 24 hours, most times it will be much quicker.
- Be patient and work with me. This is new to me also, and I am highly confident it can be beneficial in the long run. But like any problem solving exercise, or continual improvement initiative, obstacles or issues arise. When/if they do, alert me and we will address promptly. Since you are all from the Quality Assurance discipline, you are not new to this type of process; trying a new strategy to improve the overall product.
- Constraints: Unfortunately I have to work under some administrative constraints. In a perfect scenario, you would not have the 6-week session constraint, you'd be able to start the course anytime within a semester and complete the course under you own plan within an entire semester. Don't worry about the timing. Ideally I'd love to see everyone move through quickly and finish well before 6 weeks. Keep in mind if you DON'T finish in 6 weeks, I will grant an INC grade and you can complete the course regardless.
- Feel free at any time to offer suggestions, complaints, etc. But please use one of the discussion boards. I do not mind getting and responding to e-mails, but my goal is to capture all issues, etc. within the course shell. If you feel you need to communicate via e-mail vs. discussion board, please do so!

You can now proceed to Module 1. I suggest reading the chapter in the text first, then attempting the pre-evaluation. I suggest this strategy for the entire course. If you want to be aggressive and proceed directly to the Mid Course evaluation, by all means do so! - However I'd recommend reading Chapter 1 - 4 first. Best of Luck, Enjoy and communicate with me often!

REVISING MANUSCRIPTS FOR PUBLICATION

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Abstract

University-level instructors who aspire to tenure must establish a legitimate publication record and develop credible credentials in their fields. Publishing, however, may be a major obstacle for those who are technically adept but linguistically challenged, for non-native speakers of English struggling to develop an academic voice, and for those who become discouraged when their work is returned for revision with copious reviewer comments. The keys to publishing involve perseverance and an understanding of revision techniques. While tenacity involves personal character traits, this paper can help with the latter by explaining revision strategies regarding grammar, structure, source usage, graphics, and ethical considerations.

Introduction

Clear writing in the engineering professions—industry and academia— is a necessity, for both pragmatic purposes and more ethereal considerations; engineering poetry, for example (Poetry, 2013). Writing is not ancillary to the field; to the contrary, it is crucial for documenting technical and design processes that result in an enhanced quality of life as well as generating the "body of knowledge" of a particular area. "Engineers are artists," suggests *AutomationWorld* contributing editor James Koelsch, "even if they don't fit the popular notion of the term. It's just that their medium is mathematics, rather than paint or words" (2011). In fact, the Greek root of "technology," *techne*, translates as "art" or "craft" (Definitions, 2001-2018), and the Latin root of "engineer," *ingenium*, means "maker" or "ingenious," specifically, a clever maker of war machines (What, n.d.) As ingenious artists, engineers create with words and visuals in addition to mathematics. And writing creates knowledge (Winsor, 1990). Engineering innovation is for naught if not communicated.

Traditionally, engineers publish in conference proceedings, trade journals, and professional journals, among others, such as lower-circulation, company-specific publications. Virtually anyone who has submitted a manuscript to a publishing venue has received the judgment "revise and resubmit," along with reviewers' comments dissecting the paper. Especially for new authors, this may be disappointing. Authors like to think that their writing is clear, original, and engaging. To find that readers think otherwise is discouraging.

Reviewers, who are usually content area experts, read a submission with several criteria in mind, such as originality/contribution to the field, scholarship, research methodology (if appropriate), audience appeal, length, and appropriateness of graphical materials (AJAE, n.d.). They have several possible recommendations: publish as is (very rare), publish with minor revisions (less rare, but still uncommon), revise and resubmit (the most common), and reject (usually reserved for papers that are poorly written, inappropriate for the journal, or have major flaws). The revise-and-resubmit category also involves another round of peer review. "R & R" is shorthand to inform authors that reviewers see potential in the manuscript and are giving writers another chance to clarify the information. A revision can range from grammatical tidiness to a major overhaul. Generally, reviewers offer constructive criticism intended to strengthen the paper as well as reflect positively on the publication.

This paper gives detailed information, with emphasis on IAJC journals, about revising a manuscript for publication and looks at writing style, structure, source usage, graphics, and ethical considerations. While much information is available in print and online about the mechanics of writing, reviewers of manuscripts submitted for publication may question whether authors actually access those materials, given the overall quality (Schultz, 2010). Based on this author's more than three decades of experience as a manuscript reviewer, technical editor, and proceedings editor for several technical organizations, this paper offers a quick, easily digestible guide to revision strategies. While many authors tend to regard revision as a mechanical task that primarily consists of cosmetic changes, they can benefit by considering the act as a noun: RE-vision—seeing the work anew from an aesthetic distance. Revision involves much more than mastering comma usage; it, like the original draft, manifests the Aristotelian concept of *inventio*, or "discovery" (Aristotle, trans. 1954), the primary act of rhetoric. Engineers practice *inventio* in relationship to physical objects, but they also engage in discovery by writing about those objects.

The Importance of Grammar

While engineers are stereotypically perceived as unimaginative writers, an average engineer spends 50% of his/her work time writing or otherwise communicating, producing many types of documents, including technical reports and papers, memoranda, email, proposals, in addition to presentations (Smelser, 2001). Just as engineers view details as essential to the design process, the same holds true for the writing process. This is especially applicable to grammar.

Grammar is the structural component of language that produces meaning. Grammar captures a writer's thoughts and conveys an interpretation of those ideas to a specific audience. Thus the ability to manipulate and control language is an essential characteristic of meaningful communication. As Jana Johnson suggests, "Just as an improperly configured telephone wire can cause static during a phone conversation, improper grammar can likewise affect the meaning and clarity of an intended message" (2014). Static includes linguistic anomalies such as improper word choice, awkward sentence structure, and punctuation errors that affect meaning, as in this viral Internet example: "Let's eat grandma" and "Let's eat, grandma" (2015). The comma makes the difference between cannibalism and a pleasant family dinner. As the caption reads, "Punctuation saves lives!" While this example is amusing, it effectively makes the point that a tiny punctuation mark can make a world of difference in meaning. Hence authors must familiarize themselves with basic punctuation and acknowledge that a slip can produce an unintended result. In areas such as software engineering, correct punctuation is critical (Stotts, 2013).

Non-native speakers of English (NNS), in particular, may have difficulties writing in a foreign language. This is a significant issue, as 2010 statistics from a National Science Foundation report indicate that 49% of engineering faculty and 51% of computer science faculty were born outside of the US (2014), speaking a language other than English. As Belcher notes, most academic journals require fluency in English and act as linguistic "gatekeepers" (p. 1), to the disadvantage of international authors (2007). While the situation may change in the future and enfranchise more NNS, at this time editors must contend with the status quo, which requires a high level of competency in English. The following examples from technical manuscripts demonstrate a number of representative linguistic anomalies that authors exhibit; unless otherwise noted, all examples are from papers submitted for publication.

Example #1: Repetitive Phrases

"Using these technics, students were able to come up with different styles of illustrations to come up with the final proposal."

Using the same verb twice in a sentence is not necessary; the author needs to find a synonym, perhaps more vibrant than "come up with." Since Word includes a thesaurus, this is not a difficult task. Perhaps the writer was rushed and did not carefully proofread the paper or lacked another verb possibility. Also, "technics" refers specifically to a firm that manufactures speaker systems, amplifiers, turntables, and other products relating to music. As a short form of "techniques," it is inappropriate for a scholarly paper.

Example #2: Using an Incorrect Word

"Rote learning is a type of learning in which students literately memorize key facts."

The word "literately" is incorrect; the author apparently means "literally." Again, careful proofreading is necessary before submission.

Example #3: "ESL" Errors

"There were different evidences that showed how successful this project was."

Adding a plural ending to a "noncount noun" is a common mistake in papers written by NNS. "Evidence" is spelled the same whether it is singular or plural. Other common noncount noun errors in technical papers include "softwares," "researches," "equipments," and "informations."

"First row and first column are reserved as a way of checking for coding errors."

"At the end, this project represented a good preparation for all the to better access the job market."

Omitting or adding articles is another very common error in NNS writing. For native speakers, articles are more intuitive than prescriptive, but NNS may speak languages that do not include "a," "an," or "the," making it very difficult to understand usage (Miller, 2005). A typical rule of thumb involves countability; use articles for words that can be made plural and not for collective nouns. However, this often changes according to context (Mitchell, 2004) and is not a reliable guideline.

Example #4: Published Samples

"While systematic depicted above is worried about how things are different, practical science is worried about how things are indistinguishable." (Someswar & Anjaneylul, 2017)

"Recent years, with the increase of Oil-gas long distance pipeline constructions, then the water and soil disaster is concerned gradually by employees." (Zhan, Chen, Tang, Shi, 2017)

Both sentences are excerpted from articles published in open-access, online journals, often the choice of NNS, due to a less rigorous—or, more likely, non-existent—peer review process. These journals have proliferated in the last decade and engage in little, if any, editing activity. Both of these sentences are jumbled English: in the first one, science cannot "worry"; that is a human characteristic. The second is very difficult to understand, and most readers probably would not wade through the entire article.

All of these examples exhibit the need for more careful writing, proofreading, and, in the case of NNS, assistance from a native speaker, preferably someone who has a publication record, a facility for writing, and is willing to help fledgling writers. Another alternative is to consult a short, reader-friendly grammar guide such as Strunk and White's *The Elements of Style* (2000) or William Bradshaw's *The Big Ten of Grammar: Identifying and Fixing the Ten Most Frequent Grammatical Errors* (2012). The advice in these is much easier to digest than longer, very detailed grammar handbooks.

Faulty Paraphrasing

Some articles show a high percentage of matching text in computer scans because of the writer's inability to appropriately paraphrase. Most authors learn that paraphrasing consists of rewriting a passage "in your own words" but not the extent of the revision. For example, an editor was researching a reference in a submitted manuscript because the reference was not in the required format; the following example is the opening paragraph of the manuscript:

"A Health Safety and Environment (HSE) survey found that a third of accidents in the chemical industry were maintenance-related. Lack of, and deficiency in permit-to-work systems was cited as the largest contributing factor."

To the editor's surprise, she discovered a nearly identical paragraph in the cited article:

"An HSE survey found that a third of accidents in the chemical industry were maintenance-related. Lack of, and deficiency in, permit-to-work systems was cited as the largest single contributing factor."

Changes are minimal, limited to spelling out the survey title, wrongly deleting a comma, and deleting a word. The rest of the article followed a similar pattern. Rather than writing, this author was simply assembling paragraphs from several websites, practicing what is dubbed "patchwork plagiarism" (Direct, 2018). Paraphrasing poses a challenge in engineering, since the literature of any given technical field is littered with commonly used phrases (see, for example, Most, 2018). While writers cannot avoid the phrasing, they can avoid mimicking the sentence structure of the original. Computer scans, however, will flag the phrases as plagiarism. Conscientious editors will ignore the highlighted text.

Real paraphrasing consists of retaining the central idea but using different words; if that is not possible, adding quotation marks around borrowed phrases signals to the reader that those words belong to the original author. According to the federal Office of Research Integrity (ORI), "The ethical writer takes great care to insure [sic] that any paraphrased text is sufficiently modified so as to be judged as new writing" (Office, Examples, n.d.). Many university library websites offer useful information regarding paraphrasing. The Purdue OWL, for example, suggests a simple process. Although this is written for students, faculty new to publication may also benefit:

1. Reread the original passage until you understand its full meaning.
2. Set the original aside, and write your paraphrase on a note card.
3. Jot down a few words below your paraphrase to remind you later how you envision using this material. At the top of the note card, write a key word or phrase to indicate the subject of your paraphrase.
4. Check your rendition with the original to make sure that your version accurately expresses all the essential information in a new form.
5. Use quotation marks to identify any unique term or phraseology you have borrowed exactly from the source.
6. Record the source (including the page) on your note card so that you can credit it easily if you decide to incorporate the material into your paper (Paraphrase, 2009-2018).

Appropriate Structure

Structure refers to the organization of content. Some papers, such as empirical research-based papers, follow a predictable formula that includes these headings: Introduction, Methodology, Materials, Results, Discussion, Implications for Future Research (if appropriate), Conclusion, References. These types of papers are common in engineering and science fields, as writers continue to develop technical knowledge. Not all papers, however, involve reporting data gleaned from experiments or surveys. Some are simply expository: explaining the development of a new course or curriculum, detailing a case study, describing accreditation challenges, and a myriad of other topics. Such diverse subjects do not conveniently conform to a pattern, as do research studies. Authors need to ensure that sections logically flow, always keeping the purpose of the paper and potential readers at the forefront.

Reviewers may ask authors to engage in substantive editing, which involves reconsidering elements larger than grammar and punctuation. In fact, according to Provenzale and Stanley's thoughtful piece on peer reviewing, several reasons for a manuscript receiving a "revise and resubmit" decision involve substantive issues: " first, the reported data need to be analyzed in a different manner; second, additional data are needed; third, the authors have failed to appropriately take certain study factors into account; or fourth, the authors have not appropriately discussed their results against the background of previous studies" (p. 96, 2006).

The latter point is particularly important. A literature review is necessary for context; indeed, authors should always conduct a thorough review of available literature prior to writing. Since most editors are interested in publishing articles that advance knowledge in the field, papers that simply reinvent the wheel, due to the author's lack of research, are probably destined for the reject bin. For example, assume that an engineering instructor adds a writing-across-the-curriculum element to a sophomore project course. She considers that this is a unique approach to linking communication skills with technical content. However, a simple Google search yields an unfiltered score of 122 million sites. This is hardly a "unique" approach. Conscientious writers will exercise due diligence in background research.

Technical writer Kathleen Frost offers a thorough checklist for substantive editing, including the following:

- Organization (logical)
- Complete information, with "appropriate level of detail for the audience"
- Clear context
- Appropriate graphics that "enhance and clarify textual information" (n.d.)

Substantive editing also includes adhering to the publication's prescribed format and ensuring that reproduced graphics are used by permission.

Outside Source Usage

Acknowledging outside sources is a professional obligation, and the literature about plagiarism is replete with examples of those who have ignored this responsibility. For example, historian Stephen Ambrose, author of *Band of Brothers* and dozens of other books, experienced heavy criticism when his curious writing style was exposed. He would use the words of others and then add a footnote indicating the source. Those words, however, were unadorned with quotation marks, so a casual reader—which includes most of Ambrose's audience—would naturally assume the writing to be that of "Uncle History" (Plotz, 2002). While Ambrose initially blamed the incident on "faulty attribution," subsequent investigation revealed a distinct pattern: stealing the words of others *was* Ambrose's writing style. *Slate* magazine's David Plotz equates this activity to vampirism: "The plagiarist violates the essential rule of his trade. He steals the lifeblood of a colleague" (2002).

Editors tend to assume that authors are acting responsibly, although many recent cases, including some reported by reviewers, have resulted in the use of detection software to scan incoming submissions. Therefore, it behooves authors to be meticulous about references and include citations, in the appropriate style for the publication, for any material from outside sources, and to be conscientious about clearly marking quotations. IAJC journals require APA style. Authors unfamiliar with a particular style should not simply guess but rather consult a reliable website for examples. The Purdue OWL (owl.english.purdue.edu/owl), for example, gives sample entries in three different styles: APA, MLA, and Chicago. It is a very handy reference. Authors should also note that editors and reviewers have little patience for those who ignore directions and use IEEE style instead of APA.

Reference all materials used as sources, including quotations, paraphrases, and summaries taken from published items or unpublished conference papers, PhD dissertations, master's theses, speeches, etc. This includes the Internet; in fact, under the provisions of the 1989 Berne Convention, *everything* on the Internet is protected by copyright, whether or not the copyright symbol appears (Skvarka, 1996). However, there is no need to reference tools used, such as software programs, or incidental mentions of technology, such as a programmable logic controller. Simply stating the manufacturer and product model number is sufficient.

Graphical Elements

In addition to text, authors need to carefully consider graphical materials, which constitute another language in technical writing and is essential in design documents. US copyright, in addition to specifying allowable amounts of text that authors can freely use, also limits use of graphics without permissions:

Copyright protection subsists, in accordance with this title, in original works of authorship fixed in any tangible medium of expression, now known or later developed, from which they can be perceived, reproduced, or otherwise communicated, either directly or with the aid of a machine or device. Works of authorship include the following categories: (1) literary works; (2) musical works, including any accompanying words; (3) dramatic works, including any accompanying music; (4) pantomimes and choreographic works; (5) pictorial, graphic, and sculptural works; (6) motion pictures and other audiovisual works; (7) sound recordings; and (8) architectural works. (US Copyright, 2016, p. 8; emphasis mine)

The law further delineates the items listed in 5 above as "diagrams, models, and technical drawings, including architectural plans" (p. 108), which includes graphics in technical papers and books. Figure 1 shows an example of a graphical aid from a paper submitted for publication. While it does include a caption, the source of the photos does not appear, leading readers to assume that the author is the photographer. Even if the caption includes a reference, that is insufficient: the author needs explicit permission to avoid accusations of copyright infringement. Journals cannot reproduce graphics owned by another copyright holder.

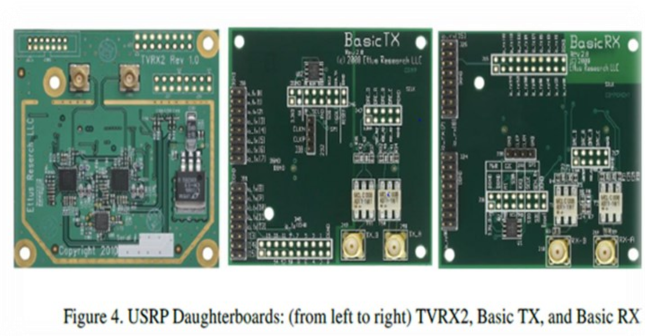

Figure 1. Example of purloined graphic.

Obtaining permission is usually a simple process: the author contacts the copyright holder (in the case of Figure 1, the website manager) and explains why s/he is seeking permission. If the reason is for academic publishing purposes, usually permission is granted. The author then adds a "Reprinted with permission" statement to the figure caption and sends the permission notice to the editor. Note, however, occasionally permission may be fee-based, especially if the item requested is archival or of historic value or appeared in a high-profile publication.

Ethical Considerations

Maintaining an ethical perspective is an essential component of publishing, applicable not only to publication staff but to authors as well. With the advent of open-access, online publishing, ethics has become even more important in preserving the integrity of academic publications, currently threatened by literally thousands of bogus items—predatory and hijacked journals—that promise quick publication with no time-consuming peer review, all for a fee. This practice results in articles of questionable accuracy and veracity and can cost authors hundreds of dollars, in addition to potentially affecting scholars' reputations (Coan, 2017) and having a negative effect on promotion and tenure deliberations (O'Donnell, 2018).

Many of the items appearing in a list of "potential" predatory journals and publishers are technical in nature, such as the *International Journals for Sciences and Higher Technologies* or *Engineering Research Publication* (Beall, 2017). Jeff Beall, a University of Colorado librarian, was one of the first to draw attention to solely open-access, online journals that basically publish anything for a fee. Beall's list has since been supplanted by Cabell's blacklist, a for-fee service (Anderson, 2017). Engineers who publish, including practitioners, faculty, and graduate students, should be wary of publications that promise quick publication and charge high fees, especially those soliciting manuscripts via email.

Legitimate publications generally adhere to ethics as formulated by the Committee on Publication Ethics (COPE), available on its website (publicationethics.org); many of these guidelines are also applicable to authors. In addition, publishers' websites include ethical guidelines for authors. Wiley, for example, has an online booklet, *Best Practice Guidelines on Publishing Ethics: A Publisher's Perspective*, that explains a number of issues relating to writing and research integrity: fabrication, falsification, plagiarism, image manipulation, duplicate publication, intellectual property rights, copyright (2014). For this editor, who has more than 30 years of experience, the following three areas are important ethical considerations for authors: originality, text recycling, and online editing services.

Originality

Authors should be aware that most journals now use some type of plagiarism detection software to determine originality. CrossCheck is common, as are Grammarly, Plagramme, Unplag, Noplag, Turnitin, and PlagScan, all fee-based services (Top 12, 2017). IAJC journals use PlagScan, which compares the submission to a large database of millions of academically oriented sources. It fares well in the software review community and outperforms a number of free services (Bailey, 2011). The user simply uploads a file; PlagScan examines it and produces a report, available as a .pdf or an annotated Word document, which an editor can save and forward to the author. Across the top of the report is a banner summarizing the analysis (Figure 2).

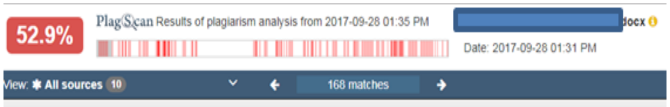

Figure 2. Example of PlagScan summary report banner. Reprinted with permission.

Clicking on the word "View" in Figure 2 yields a numbered list of sources (Figure 3, partially obscured to maintain confidentiality). Clicking on a source will retrieve the actual article.

Figure 3. Example of PlagScan clickable source list. Reprinted with permission.

The actual report, excerpted in Figure 4 with asterisks replacing identifiable content, is color-coded:

- Red: matching text; the author has used words verbatim from a source, without attribution
- Blue: a near match; the author has made cosmetic changes to the original
- Green: a legitimate quotation, with attribution (not shown)

Clicking on a colored section reveals the original document; users can also click on this box to access the source (Figure 5). As is clear from the PlagScan report, this is not an original paper. The author has used substantial portions of a previously published conference proceedings paper as a basis for the "new" one, raising a major ethical question regarding recycled text. The author was asked to completely revise the text prior to the peer-review process. While useful, detection software is far from infallible. An editor's eye is also necessary, as these programs flag *all* matching text, including references, common terminology in a given field, and recycled authors' biographies. They also have limited databases, only checking Web-based sources in languages that use the Roman alphabet, and only examine text, not graphical elements. Furthermore, most programs give "false positives," marking as matching text those sections that are legitimately attributed (Dyrud, 2014). An editor is an essential part of the process, especially to rule out false positives.

Although some authors have tried (Beall, 2013), deceiving detection programs is difficult. As a resource article by CrossCheck producer iThenticate notes, "Most attempts to outsmart plagiarism detection software require effort be-

Teaching the operation of ************ can be improved by using new methods in conjunction with the traditional methods explained *********** textbooks. These supplementary methods include various hands-on and simulation tools which can be introduced in a ****************. Such tools are generally needed for helping students understand the operation of complex mechanical systems like the ********* ************ of a passenger car. While students can obtain some information about the operation of an ********* ********* in a textbook, teaching experience has shown that it is not enough. Furthermore, making a connection between the textbook illustrations and the real world application may not be easily accomplished. For a novice learner nothing can replace the direct observation of the operation of an ******* ************ the way a physical model or a related computer simulation can do. To address this need, the present paper described different theoretical, simulation and experimental methods where the operation of

Figure 4. Excerpted text with color-coded matches. Reprinted with permission.

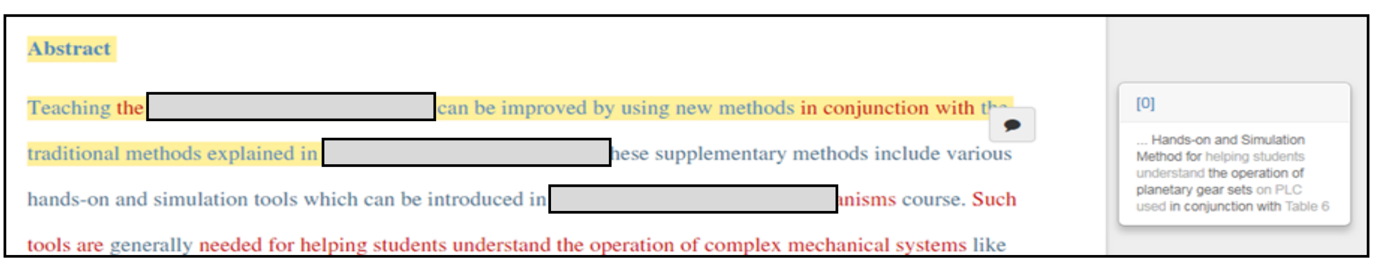

Figure 5. Example of annotated text. Reprinted with permission.

yond what is required to properly cite or paraphrase source material. Software engineers estimate that in order for duplicated text to pass a plagiarism detection scan, the author would need to rewrite or revise every third word" (iThenticate, 2013).

Despite these shortcomings, detection software has streamlined the initial review process. Of course, authors are the key figures. By not recycling previously published materials, authors allow a publication's staff and reviewers to quit worrying about originality issues and copyright infringement and focus more on content and contribution. Authors can use detection software programs to check their work prior to submission. Since many universities already subscribe to Turnitin to scan student work, an author can easily review his/her own work and identify areas for improvement. Doing so also simplifies the work of editors and reviewers.

Recycling Conference Papers

In the past, publishing modified conference papers in a professional journal was a common practice, primarily because proceedings were available only to a limited audience of conference attendees. With the advent of the Internet, however, this has changed, and proceedings are now widely available online, although some sites require a login. University libraries also provide access. According to Tamsin Harwood, legal counsel for Wiley Publishing, one of the most common problems facing publishers involves repetitive publication, either dual, redundant, or self-plagiarism, all of which involve republishing material without attribution or acknowledgment of prior publication (n.d.). Publishing an unrevised conference paper in a journal is an example of duplicate publication.

Conference proceedings are a major publication outlet for engineers (Linsee, Larevière, & Archambaut, 2008), and the temptation to make a few cosmetic changes and then submit a manuscript to a journal is seductive. However, some professional societies have established policies regarding this issue. The IEEE Communications Society, for example, notes that "Conference papers cannot be republished without substantial additional technical material. The meaning of 'substantial' is left at the discretion of the Editor [sic]" (Conference, 2017). In a study of more than 300 journals related to computer science, Zhang and Jia found that very few editors would publish conference papers verbatim; most require new content, ranging from 20% to 70%. In addition, the peer review process would be "more rigorous" (2013, p. 193), even if the proceedings were peer reviewed. They conclude, "Those [journals] that do republish conference papers will generally only do so if the paper has been substantially reworked to include additional detail which could not be included in the conference paper" (p. 195).

Authors should follow the advice of the ORI and avoid submitting unrevised conference papers to professional journals, since it may be copyright infringement. They should "adhere to the spirit of ethical writing and avoid reusing their own previously published text, unless it is done in a manner that alerts readers about the reuse or one that is consistent with standard scholarly conventions (e.g., by using of [sic] quotations and proper paraphrasing)" (Office, Text, n.d.). When an author publishes a paper, s/he signs a copyright transfer agreement and no longer owns the work. Despite popular opinion to the contrary, the practice of reusing prior work is unethical and may have legal implications. In the literature, it is referred to as "self-plagiarism" or "text recycling" (COPE, n.d.) when an author simply submits an article that has sections repeated verbatim, or nearly verbatim, from a prior publication, indicating "a certain degree of scholarly laziness" (IEEE, 2018).

Reusing text without permission may constitute copyright infringement. US copyright law clearly explains the boundaries of "fair use," based on "the amount and substantiality of the portion used in relation to the copyrighted work as a whole" (US Copyright, 2016, p. 19). Under the fair use doctrine, quoting a small portion of an article or book for academic purposes is allowable; quoting an entire work, regardless of length, is not. Statutory damages can include a fine up to $150,000 for unauthorized reproduction (US Copyright, 2016). To avoid copyright infringement, author have several options:

- Check journal guidelines/policies for information regarding this issue
- Keep the central idea but completely rewrite the paper
- Reference repeated portions as per any other source material and use quotation marks as appropriate
- Seek permissions from the original publisher to reprint certain sections, especially graphics
- Discuss the situation with the journal editor/ associate editor

Repercussions for republishing articles may be severe, including rejection; retraction, if the article has already been published and the issue later comes to light (COPE, n.d.); loss of publishing ability in that journal or other organizational publications and subsequent appearance on a "prohibited authors list" (IEEE, 2018). Some editors will also notify an academic author's department chair, which may result in demotion or termination (Karabag & Berggren, 2012). Professors who violate academic integrity may also find themselves the object of local news stories, as happened to George Carney, an Oklahoma State University geography professor, who was featured in both the local university paper and *The Chronicle of Higher Education* articles describing a 30-year career littered with plagiarized materials (Professor, 2005).

Online Editing Services

Some authors, especially those desperate to publish or non-native speakers concerned about their English skills, may turn to online editing outlets in an attempt to improve their manuscripts. Services that offer proofreading and editing, for a fee, are rampant on the Internet. Proof-Reading-Service.com, for example, charges £10.99 ($15.42) per thousand words, roughly four pages double-spaced (Prices, 2016). ProofreadingPal.com bases its pricing structure on word count and turnaround time, although its website does not give actual figures (Pricing, 2006-2018). EditorWorld's charges are similar; the site includes a calculating function: the user simply enters an article's length and the calculator determines the amount of time necessary and gives a cost estimate. A 10,000 word article, for example, will take two days and cost $240 (Prices, 2018).

Some open-access, online journals offer editing services, for a fee. However, authors should avoid publishing in these journals, due to legitimacy issues, and especially avoid editing services that describe their assistance similar to the *Canadian Chemical Transactions*: "If reviewers recommend *for* extensive English editing for a manuscript *[missing punctuation]* then authors should *take* the English editing service. We charge $8-10 *dollor* a page (one page =300 words excluding *titile*, author's name and affiliations, and references) *depends* on editing requirements" (English, 2018; emphasis mine). Six errors in two sentences is not a positive reflection of their editors' English competence. Few studies exist on the accuracy and efficacy of these services and the credentials of the editors, especially in regards to editing for professional journal submissions. Australian educator Lisa Lines has examined the prevalence of substantive editing in graduate students' theses and dissertations and concluded that the practice devalues degrees and amounts to plagiarism (Lines, 2016).

Online editing services range from simple proofreading to complex substantive editing and can obscure authorship, since the paper passes through many hands prior to submission. In fact, George Lozano notes in his study of the ethics of these services, "other than data gathering, 'editing services' can be deeply involved with all aspects of producing a paper, from the beginning to the end, starting with a proposal, continuing with developmental editing and ending with copy-editing and proof-reading. It is clear that at least in some cases, the 'editing service' and the author(s) essentially co-write the paper" (2013, p. 374). International writers, concerned about the quality of their English language skills, mostly use the services, which can be very costly, especially for lengthy documents. Extensive use of online services may result in an impressive publication list, but it raises vexing questions: How much of the output is actually attributed to the writer? If an editor has rearranged the structure and content, as well as sentence structure and vocabulary, who has "written" that article? According to Lozano, "These days, an extensive publication record is no longer predicated on the ability to write" (2013, p. 375).

Conclusions

From a practical viewpoint, authors in all fields would benefit by regarding their manuscripts as "works in progress," at least through the peer-review process, and accepting revision suggestions with an open mind, avoiding defensiveness. To avoid damage to fragile egos, authors will be better served psychologically by simply assuming that any submission will require a revision. Being tied to the message rather than the exact wording is paramount, as is seriously considering reviewers' comments when revising. While the process of rewriting is, in some respects, easier than initial composition, it still poses a major challenge.

For engineering professionals in particular, writing is necessary to document the design process and create knowledge. According to Dorothy Winsor, "writing is what engineers do . . . . They inscribe a written representation of physical reality and then use more writing to build agreed-upon knowledge" (1990, p. 68). The real key to producing readable and engaging writing is for authors to train themselves to read with an editor's eye, maintaining an aesthetic distance and looking at the material in a new light. Revision involves much more than bouncing through a manuscript changing punctuation; it is re-seeing the material from a different perspective.

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Biography

MARILYN DYRUD retired in spring 2017 as a full professor in the Communication Department at Oregon Institute of Technology, where she has taught for four decades. She has been a member of ASEE for 32 years and is active in the Engineering Ethics Division as past chair, and the Engineering Technology Division as the current program chair. She also chairs the newly formed Ethics Task Force. She is an ASEE fellow (2008), winner of the McGraw Award (2010), winner of the Berger Award (2013), and the communications editor of the *Journal of Engineering Technology*. In addition to ASEE, she is active in the Association for Practical and Professional Ethics, the Association for Business Communication, and serves as a technical and proceedings editor for IAJC journals and conferences. Dr. Dyrud may be reached at Marilyn.Dyrud@oit.edu

INTEGRATING ENGINEERING, MANAGEMENT, AND INFORMATICS PROVIDES STUDENTS WITH EXCEPTIONAL BENEFITS

Saeed Foroudastan, Middle Tennessee State University

Abstract

The Master's of Science of Professional Science (MSPS) program at Middle Tennessee State University (MTSU) is a unique interdisciplinary degree that educates students in science, technology, engineering, and mathematics (STEM), while simultaneously including core business classes. This forward-thinking degree is one of over 300 programs that form the nationally recognized Professional Science Master's. The MSPS Engineering Management (EM) program at MTSU represents the future of the engineering technology degree. Engineering and management have been related for quite some time, but many graduate programs fail to capitalize on the need to foster that relationship in students before they enter the professional world. This EM program provides students with a skill set that will make them standout to employers and be unmatched by the competition when entering the workforce. It requires students to take courses in project management, safety planning, research methods, and technology trends. Additionally, students receive credit towards the Project Management Institute (PMI) and become certified in both lean and six-sigma methodologies.

The EM program at MTSU also gives students the opportunity to bridge the gap between engineering and informatics. Being able to exchange information between peers in the workplace is invaluable, but unfortunately not all engineering students are able to do that. All of the required courses in the EM program have applications of informatics in order to create a well-rounded engineer. The program is rounded out with an internship instead of a thesis. Hands-on experience outside the classroom for students to get a taste of their future and test their knowledge is highly important to this program. In return, students gain valuable experience and further those relationships between engineering, management, and informatics in a real industry setting.

Introduction

In its 2017 report on professional development for science, technology, engineering, and mathematics (STEM) graduate students, the Council of Graduate studies recommended, "Greater alignment among employers and universities to ensure that the professional development experiences provided to advanced STEM graduate students are relevant, and where possible, tailored to employer needs" (Denecke, Feaster, & Stone, 2017). Professional Science Master's (PSM) degree programs were started in the late 1990s to meet industry's demand for STEM graduates, who also had business professional skills (Professional Science Master's affiliation, 2018). The PSM degree is a two-year interdisciplinary graduate program funded by the Alfred P. Sloan Foundation and is designed to educate students with training in STEM disciplines, combined with training in management and professional skills, such as communication, leadership, and working as a team (Foroudastan & Prince, 2015). The EM degree has a unique ability to round out the students' diverse skill set, while learning the core knowledge needed. Not only do students graduate with a great amount of engineering knowledge, but a great business core as well. The program ends with an internship rather than a thesis so that students are able to gain valuable experience while still learning.

The PSM program takes form at Middle Tennessee State University as the Master's of Science in Professional Science (MSPS) program. Beginning in 2004, the MSPS program was the first of its kind in Tennessee. The MSPS program serves as the national model for PSM programs and is one of the fastest growing and widely recognized graduate programs at MTSU. When it was originally launched, this program contained two concentrations: biostatistics and biotechnology. After profound success, the program expanded its available concentrations to include actuarial science, geoscience, healthcare informatics, and, most recently, engineering management (Foroudastan & Prince, 2015). The goal of the MSPS program at MTSU is to provide a much-needed blend of science and business. The program consists of a required 36 hours, with 21 hours coming from core concentration courses and 15 hours of common business courses. MSPS is able to partner with the College of Basic and Applied Sciences, the College of Behavioral and Health Sciences, and the Jennings A. Jones College of Business. Each concentration has specifically selected core courses designed to provide the students with the skills necessary to succeed. Business courses are taught by certified business instructors and science courses are taught by certified science instructors so that students receive education from experts in their respective fields. The business courses include probabilistic and statistical reasoning, business law, accounting, leadership and management, and managerial communication. Students that complete this program prove to be a tremendous asset to the workforce, having education from both sides instead of having to pick up all the needed extra information while already on the job.

Once of the most beneficial aspects of the program for the students is the internship at the end. Students must complete at least 250 hours in their respective fields of study. During these 250 hours, the students hopefully make many connections, are able to get their proverbial foot in the door, and gain valuable experience. On average, seventy-five percent of students receive employment from their internship sites (Foroudastan, 2015). Many employers that have established a relationship with the MSPS program at MTSU have hired these graduates and continue to be impressed with the young professionals that the program produces.

The MSPS program has created valuable partnerships with local industries in the immediate area and continues to grow those relationships to support MSPS students in their quest for a higher degree and job offers. These industries find extreme value in the kind of skilled professionals that the program graduates year after year. In order to support the program and have a hand in educating students, some industries participate in an advisory board and help build the program each year. These relationships with industry are a vital part of what helps make the MSPS program so successful for students and so beneficial for employers.

The success of the Master's of Science in Professional Science program has gained recognition at both the local and national levels. In 2010, the Tennessee Board of Regents awarded the MSPS program with the Academic Excellence Award (Middle Tennessee State University, 2010). Furthermore, the Council of Graduate Schools in Washington, DC, uses MTSU's MSPS program as a model for traditional PSM programs. The program currently has a retention and graduation rate of 95% (Middle Tennessee State University, 2018).

Engineering Management

The engineering management concentration is the newest of the six available MSPS concentration options. The concentration was added after the need for a concentration that combined technical skills, such as engineering, with management and leadership skills was identified. The goal of the EM program is to provide both the science and business content to meet this need. Another goal of the program is to provide its graduates with the skills to be competitive and highly valued in the engineering industry. A new type of scientist is created through this program. This new type of scientist is highly sought after by employers, and it stands to be the future of engineering technology.

Undergraduate students in the Engineering Systems and Manufacturing programs can also participate in the Engineering Management program. Students with a similar STEM degree can also be successful in this program. This is because of the management component of the program. This component is applicable to many industries besides engineering. EM students take courses in project management, safety planning, research methods, and technology trends. Engineering management prepares its graduates for their future careers in the management of technology and engineering in occupations such as technology managers for manufacturing operations in assembly and fabrication, healthcare, food production, and governmental research initiatives (Foroudastan & Prince, 2015). Also, students could have potential jobs as project managers for the concrete and construction industries, process control companies, and automotive industries (Middle Tennessee State University, 2018). It is through the variety of career options that the program not only combines engineering and management techniques but appeals to students of different backgrounds.

Certifications

Students gain credit towards their certifications from the Project Management Institute (PMI). This credit is earned in their project management class. In addition, students can gain full certification in lean and six-sigma methodologies. This certification is a huge asset to graduates of the EM program and really makes them stand out to potential employers. Students are awarded a Green Belt certification after the completion of a business/industry Green Belt project. The certification is extremely valuable, and the experience gaining it is, too. This certification process allows students to gain hands-on experience in their field. Employers today are looking for environmentally aware graduates and are willing to do what they can to be environmentally friendly. The Engineering Management program recognizes this need and will continue to offer classes like these to its students.

A certification in lean manufacturing is also available to students. This certification is a benefit to the students and to their future employers. Also, because of its value, the certification is becoming a prerequisite for employees and organizations. This certification allows the employee to help companies develop lean standards and learn techniques for improving processes. Also, they develop the abilities that are highly portable and internationally recognized. Having this certification enhances the students' career prospects and earning potential (Foroudastan & Prince, 2015).

Internships

Students must complete a 250-hour internship with a company that is related to their field of study. This internship takes the place of a traditional thesis requirement. While a thesis instills work ethic and proper research skills in a student, it does not provide the student with much-needed hands-on experience obtained only from real-world industrial exposure. Students assist with projects, learn company software, participate in philanthropy events, experience job responsibilities, and cultivate problem-solving skills that can be applied to overcoming everyday workplace projects and challenges. The internship takes place during the students' last semester to guarantee that they have obtained the necessary business skills and knowledge from their core concentration work and are able to bring that to the internship. Students create professional business connections and are given a chance to show their science and business expertise for a chance to receive a job offer at the end of the internship.

Partnerships

The Master's of Science in Professional Science is an interdisciplinary program developed through the efforts of over thirty professors and faculty members from three different colleges: the College of Basic and Applied Sciences, the College of Behavioral and Health Sciences, and the Jennings A. Jones College of Business (Foroudastan & Prince, 2015). This program ensures that its graduates become highly trained and prepared professionals by developing the curriculum through the collaboration of an advisory board. Members of the advisory board are made up of both backgrounds from education and the industry within a 200-mile radius of campus. The board meets a few times a year to discuss and plan to be able to keep the programs up to date. Higher education in science and business allows graduates to be able to contribute valuable skills to industries. Graduates of this program have the ability and knowledge to promote continuous innovation and growth in the science and business field.

Conclusions

The MSPS program at MTSU is one of the best. With concentrations in actuarial science, biostatistics, biotechnology, healthcare informatics, geosciences, and engineering management, this diverse degree creates great job-ready candidates in their graduates. The EM program specifically zeros in on a need that just was not being met. It offers students the unique ability to blend all the different areas of knowledge needed, such as engineering, management, and informatics. This degree enables the students to further develop and hone their soft skills and interpersonal communication that will not only allow them to become leaders in the STEM field, but also continue to propel it forward.

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Biography

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