ADVANCED GRAPHICAL COMMUNICATIONS – A COURSE EVOLUTION

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Abstract *– After a new course is introduced, its content and structure evolve to a level of relative stability. Part of that evolution is the recognition and redressing of knowledge gaps in the student body. This paper will recount the introduction and evolution of Advanced Graphical Communication (AGC), a senior-level mechanical engineering technical elective introduced in 2016 at the University of Manitoba. Geometric Dimensioning and Tolerancing (GD&T) is the core of AGC, supported by the development of drawing creation and drawing checking skillsets. Created at the request of local industry to address a knowledge gap in graduates, industry also partners with the AGC course, placing employees in the class along with undergraduate students. As the course evolved over 4 sessions, assignments were changed or modified, and support materials for various design considerations were developed. Throughout the course evolution, gaps in the students' foundational knowledge became evident; core knowledge of conventional manufacturing processes and how to select appropriate materials for a design, for example, were absent. The instructor also identified that design esoterica, such as surface finish and fit selection that are critical to a complete design specification, were not addressed in their previous studies. This paper will recount how AGC evolved and how it addressed some of the gaps using instructor-supported focused modules.*

Beyond this specific course, however, such modules could be expanded to independent micro-courses (IμC, pronounced eye-mu-cee). Specific design knowledge and skillsets will inevitably be missing in an engineering faculty, resulting in lost learning opportunities for students. IμCs are envisioned as engineering design content accessible to the student on demand, allowing discrete learning opportunities to be incorporated as a component in a course or accessed for co-curricular design competitions and capstone projects. These modules would ideally be independent of instructor support and may include physical artifacts that demonstrate specific elements within the module. Whereas conventional teaching pushes the content on the student, IμCs allow pull-based content delivery, fostering students' ownership of their learning.

Keywords: *advanced graphical communication, design esoterica, design details, surface finishes, limits and fits, material selection, geometrical dimensioning and tolerancing, teaching modules, independent micro-courses*

1. INTRODUCTION

This article will discuss how the evolution of one senior-level mechanical engineering technical elective offered at the University of Manitoba used modules to introduce various elements of design process and esoterica.

Reflecting a renewed perspective, "design is [also] a fundamental aspect of any reputable Mechanical Engineering programme, as application in the real world is what separates the practice of Mechanical Engineering from Engineering Science" [1]. This implies an expectation that graduates should have design knowledge and skillsets that go beyond the core theories and principles taught in most mechanical design courses, perhaps even the ability to bridge the divide of traditional product design and engineering design roles [2]. This is important because, without distinction to the field of engineering, studies at the University of Manitoba and internationally have found that roughly 90% of engineering graduates will enter industry [3]. Industry has an expectation that new graduates will be prepared to start work immediately, and the graduates have an expectation that they have been adequately prepared to start their careers.

Recognition of the need to prepare students for industrial employment was not always the case. Pre-1950s, engineering courses were taught primarily by practicing engineers [4]. The 1950s saw a shift in engineering curricula away from industrial applications to an engineering science bias [4]. An industry-responsive refocusing by engineering accreditation boards in 2000 saw an increased integration of design into undergraduate engineering education [5]. Since then, literature has reflected various ways to integrate and enhance design content into the curriculum. Similarly, basic understanding of manufacturing processes and how they may affect design have been enhanced by re-introducing traditional machine shop courses [6]. Some literature addresses specific skills such as the use of hand sketches as a communication tool [7], or the incorporation of aesthetics into design [8]. These are all useful and relevant in the education of engineers and reflect a broadening of perspectives beyond the core technical solution, but they do not present a complete picture of engineering design. They lack the finishing touches, the *design esoterica* that a practicing designer understands is essential to the design.

Design esoterica varies from component to component. As AGC evolved, the instructor identified that students lacked knowledge or understanding of surface finishes, tooling reliefs, the use of chamfers, fillets and rounds, the decision over component connection method, even material selection and selection of fits. These and other attributes and considerations were not included in the core elements of their mechanical design education. The field of mechanical engineering design is as diverse as the industries that mechanical engineers service; therefore, the applicable design minutiae will be diverse as well. Despite this diversity, many elements such as surface finish, fit determination, and edge treatments are common to many mechanical design fields. These design elements are anticipated by designers in industry but are not addressed in conventional theory-based machine design courses; instead, they are left to employers to teach new graduates.

Industry has recognized that mechanical engineering graduates from the University of Manitoba generally have the technical skills sought and a broad knowledge range, indicating that most students will be able to determine where they can access information on specific topics [9]. However, such design esoterica are not included in core courses in the mechanical stream. Therefore, new graduates will not recognize the absence of the subject matter from their education, and subsequently will not know where to look for information. While there may be adequate content to establish a course devoted to these elements, the diversity of information and the lack of practical experience in academia with such esoterica may make such a course ineffective. How, then, to provide these elements of design knowledge to students? One study discusses the use of module-based teaching of mechanical design [10] to facilitate the understanding and application of specific design knowledge. Though that article focused on teaching specific core knowledge of mechanical design, the idea of module-based teaching should be broadly applicable.

Through a review of any course's evolution it would be expected that knowledge gaps would be identified and could then be addressed. As AGC evolved, student feedback and instructor observations identified gaps in the students' knowledge base. In addressing these gaps, discrete modules were introduced. A basic visual glossary introduced mechanical feature terminologies. Feature identification and drawing view selection processes were introduced as scaffolds to other discussions and teachings. Design esoterica modules for surface finishes and limits and fits were developed to fill knowledge gaps. The impact of these modules has not been studied, though some students expressed that they found it easier to see a broader perspective of mechanical engineering design, and most expressed lower stress levels during the AGC course. Additionally, the instructor found that the focus of office support hours shifted from addressing knowledge gaps to addressing the core content of the course. Overall the examination of the evolution of the AGC course showed not just what gaps were present and how they were resolved, but also pointed to a broader solution strategy using independent micro-courses (IμC).

2. AGC – THE COURSE

2.1. Background

In 2015, industry representatives in Manitoba expressed that Geometric Dimensioning and Tolerancing (GD&T) should be offered in the undergraduate mechanical engineering program at the University of Manitoba [11]. Their inquiry to the Centre for Engineering Professional Practice and Engineering Education in the Faculty of Engineering at the University of Manitoba resulted in the inaugural offering of *Advanced Graphical Communications* (AGC) in the Fall 2016 session.

2.2. Core Content

In addition to GD&T, informal feedback [12] from international industry representatives had established that two additional skillsets were largely absent in newly graduated mechanical engineers: drawing creation (drafting) and drawing checking. GD&T, anchored in practice on student-created drawings and reinforced by peer-checking of student work, were the core elements of the course. One additional comment from industry resonated; regardless of co-op, internship, or summer employment history, many new graduates were not prepared for the change from academic to industrial practices [12]. A final core element of the course was thus added; students would be treated as they would be in industry.

2.3. Content Flexibility

Content flexibility allowed additional topical content as appropriate. As it unfolded, the instructor became aware of absences in the supporting knowledge base that the students had developed. These were addressed with topical modules focusing on specific issues.

2.4. Course Implementation

AGC was not only proposed by industry, it was also funded through their partnership and the course enrollment included industrial participants. The initial undergrad contingent was largely senior-year mechanical engineering students seeking hands-on skills for employment but has since included junior-year and graduate students, and students from other departments. Industry participants have included machinists, inspectors, manufacturing and design engineers, and engineering managers. To maximize opportunities for discussion and for supporting the students, the four-credit course was capped at 24 undergrads and 16 industry participants. Lectures and/or labs occupied two 3-hour evening classes per week for one term and required students to complete out-of-class assignments.

2.5. Teaching Philosophy

Put simply, the instructor's teaching philosophy reflected industrial practices; do what it takes to get it done. With the instructor's industrial experience in design, manufacturing, training and consulting, teaching was rooted in industrial practices. These practices were supported in educational theories. Reflecting on issues experienced in the instructor's undergraduate engineering education and an evolving understanding of personal learning styles, the teaching style included theory (lecture) to establish the *what* and *why* aspects, and experiential learning elements through project-based learning to build the *how* aspects. Recognizing the value of practice modeling and open dialogue in bridging the divide between academics and industrial practice, industrial anecdotes were included to reflect on the experiences of senior engineers, machinists and dimensional metrologists.

2.6. Instructor and Student Commitment

Students, forewarned that the workload may exceed any other course they have experienced during their undergraduate studies, also received the instructor's commitment to support them throughout the course. At the outset of the first session, the students were advised that this was the first time this course had been taught, and that there would be flexibility in evaluation. Support would be available in the evenings and on weekends, when students were likely to be doing their assignments, to compensate for the challenges of being the first. As the course evolved, the content and delivery largely solidified, but the commitment to support the success of the students by being available during irregular hours was maintained.

Student commitment to seeking ongoing support from the instructor, and to supporting their classmates in turn, reflects industrial practice and has been a key component to the success of the AGC course.

2.7. Data Collection

Through all four sessions, assignments received formative and/or summative evaluations as appropriate. When poor results were observed en masse for an assignment, a debrief session was used to determine the root cause(s), and to determine appropriate remedial steps. Students reported the duration of their assignments, and this was monitored by the instructor.

Support hours were tracked by the instructor. The topics of discussion were monitored to determine trends and identify issues, and were compared against assignment and examination results.

Examination responses to each multiple-choice option were monitored for the first three annual examinations to locate poorly worded questions or response options, and to determine which concepts were poorly understood and in need of content enhancements.

3. AGC COURSE EVOLUTION

Assignments have evolved, scaffold knowledge modules have been added, and student engagement has increased. The following sections map the evolution of AGC over four sessions.

3.1. Enrollment

As a new and time-consuming elective course, AGC did not reach its combined enrollment cap of 40 participants. This has allowed greater support time for each participant. Course completion rates are provided in Figure 1.

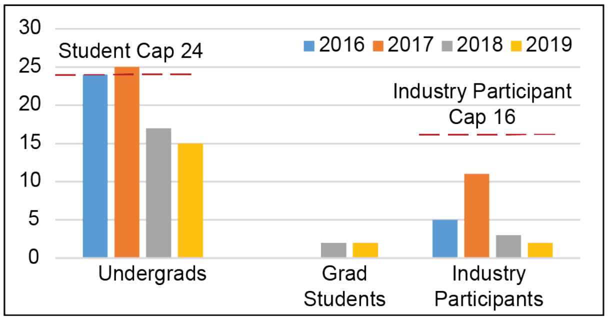

Fig. 1. Session Completion Rates

3.2. AGC Evaluations

A combination of preparatory and final assignments and a final examination were used to evaluate student progress. As shown in Table 1, the inaugural offering in 2016 consisted of three preparatory assignments followed by a significant final assignment and down-valued multiple-choice exam. Assignments shown in Table 1 are colour-coded to show which assignments have been replicated in subsequent sessions and which have become part of a progression, as indicated by colour gradient. Changes to weighting of the assignments and the final examination reflect an improved progression in complexity of the assignments. Zero-percent assignments were included so that students would have an opportunity to practice new skillsets and knowledge before being evaluated on them. Assignment descriptions are provided in Table 2. Specific findings and resolutions identified in each session are discussed in Section 4.

Table 1: AGC Session Assignments

2016		2017		2018		2019	
VB	10%	**CD**	5%	**SK**	0%	**SK**	0%
EA-V	15%	**VB**	5%	**CD**	0%	**CD**	0%
EA-D	25%	**C-V**	12.5%	**VB**	5%	**VB**	5%
IT-C	45%	**S-V**	12.5%	**C-V**	0%	**C-V**	0%
				S-V	10%	**S-V**	10%
		C-D	10%	**C-D**	10%	**C-D**	10%
		S-D		**S-D**		**S-D**	
		C-C	10%	**C-C**	10%	**C-C**	10%
		S-C		**S-C**		**S-C**	
		IT-C	20%	**IT-F**	15%	**IT-F**	15%
				IT-C	20%	**IT-C**	20%
EXAM	5%	EXAM	25%	EXAM	30%	EXAM	30%

Table 2: AGC Assignment Descriptions

	Assignment Title	Description / Focus
SK	Sketching	Three sketches of provided artifacts
CD	Drawing Checking	Attention to detail
VB	V-Block	Reproduction of existing drawing; develops familiarity with CAD software, drawing layout, documentation practices
C-V	Deodorant Container - Drawing Views	Selection of drawing views to communicate all design features
S-V	Carbide Sharpener - Drawing Views	Selection of drawing views to communicate all design features
C-D S-D	Deodorant Container / Carbide Sharpener - Datums	Progression of drawings to include datum feature identification and controls.
C-C S-C	Deodorant Container / Carbide Sharpener - Complete Drawings	Completion of drawings.
IT-F	Impact Tester - Functionality Documentation	Determine and document interfaces, material selections, tolerances, surface finish, etc. as preparation for drawing creation.
IT-C	Impact Tester - Complete Drawings	Generate final engineering drawings.
EA-V	Drawing Views - Electrical Assembly	Group analysis of assembly and components for functionality and selection of drawing views. Individual creation of drawing views.
EA-D	Complete Drawings – Electrical Assembly	Completion of drawings

3.3. Artifact Complexity

As a graphics course, physical and CAD model artifacts were integral to the teaching. Simple examples beget simple, limited solutions. In order to foster broader design thinking, assignment and examination content largely reflected common artifacts that would challenge students to simultaneously consider interplay of features. Figures 2 through 4 illustrate three of the design artifacts used. Figure 2, a v-block, was used in an assignment (VB) focused on developing CAD skills.

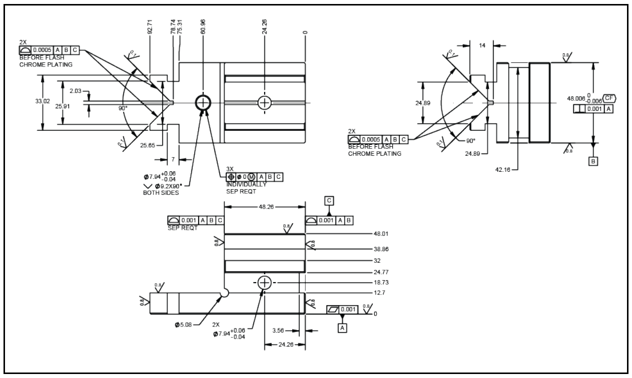

Fig. 2. V-block CAD exercise

The electrical assembly, Fig. 3, was initially used for assignments (EA-V, EA-D); however, due to the complexity, it was repurposed for drawing view and datum feature selection tutorials in subsequent sessions.

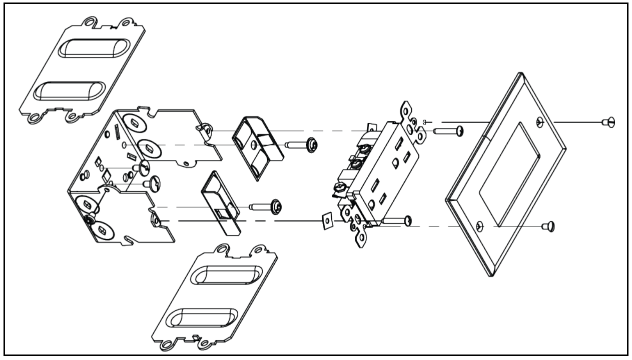

Fig. 3. Electrical assembly

The iconic image in Figure 4 was used in the final examination to evaluate students' practical understanding of geometric dimensioning and tolerancing.

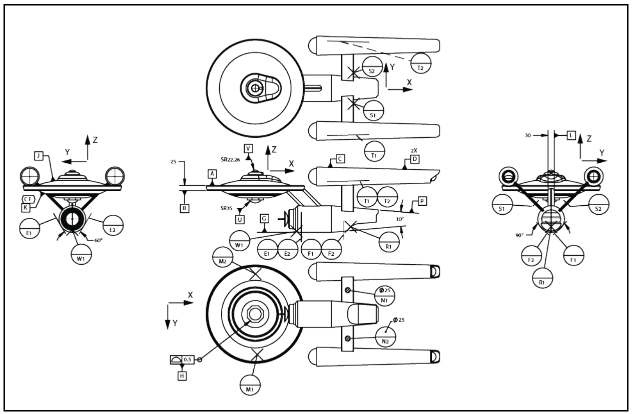

Fig. 4. Datum visualization artifact

4. FINDINGS AND RESOLUTIONS

As absences in foundational knowledge or skills were observed in each session, they were addressed through changes to the assignments, added or modified tutorials, by adding discrete learning modules, or left for future consideration. Findings (F) and resolutions (R) are summarized for each of the four sessions.

4.1. Session 2016 Findings & Resolutions

F1: The introductory graphics (CAD) course exposes students to drafting but does not teach it.
R1: Introduced Drawing Views Tutorial, focusing on the rationale behind drawing view selection, the importance of drawing aesthetics and organization. Preferred view selections and layout were indicated and explained in debrief sessions

F2: Students in senior-year mechanical engineering have had little exposure to traditional manufacturing and fabrication technologies (e.g. stamping, molding, forging).
R2: Added new design artifacts that included various production methods and included Q&A opportunities to discuss how artifacts were made. Used online videos to illustrate manufacturing methods.

F3: Students' mechanical engineering vocabulary does not include basic mechanical features (e.g. slot, shoulder), and includes incorrect terminologies (e.g. using "lathing" instead of "turning" to describe the machining process used on a lathe).
R3: Added a limited "Mechanical Engineering Glossary" presentation early in the course, and corrected students when they used incorrect terminologies.

F4: Students have been trained to see the big picture, but have difficulty differentiating the details, as was manifested in their drawing checking results.
R4: Added an "attention to detail" assignment before the V-Block assignment.

F5: As the class progressed, students were more open to expressing their concerns about entering the industrial workforce.
R5: Instructor interjected additional discussions on industrial practice and solicited more input from industrial participants in discussions.

F6: Students have had little exposure to industry artifacts, such as the electrical assembly, Fig. 3.
R6: The instructor considered whether only simple artifacts, readily familiar to most students, should be used for teaching. The instructor recognized that mechanical engineering graduates entering industry in a design or manufacturing field would benefit from a broad understanding of tools, tooling, and end products. A typical deodorant container and a carbide sharpener were added for assignments.

F7: Students expressed that they had neither understanding of what surface finish specifications mean in physical terms, nor how to select them.
R7: Introduced an instructor-supported Surface Finish Module, connecting surface finish specifications with part functionality.

4.2. Session 2017 Findings & Resolutions

F8: Students had difficulty relating 2D geometries (views) to 3D physical artifacts or CAD models and difficulty understanding projection angle.
R8: Introduced "bear in a box" first-angle and third-angle projection demonstration tools, Fig. 5, to help visualize projection angles.

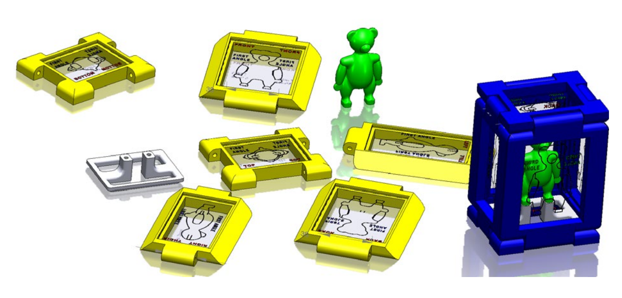

Fig. 5. Bear-in-a-box view artifacts

F9: Students had difficulty recognizing system and feature functionalities.
R9: Introduced "Drawing Planning Exercise" and modeled how to progress through the analysis of how systems, components, and features function.

F10: Students were gaining an appreciation for the scale of tolerances, but indicated they had no basis on which to decide what tolerances to assign on their drawings.
R10: Introduced "Limits and Fits" as a basis for assigning tolerances dependent upon how parts work together, and incorporated in the Impact Tester assignment. However, "Limits and Fits" standards only address size tolerancing, not location and orientation which are critical in GD&T. Developed "Tolerance Classes" training module to incorporate "Limits and Fits" in a GD&T environment.

F11: Students were selecting basic metals / materials for components in the Impact Tester based on material attributes provided in the CAD models but indicated they did not understand how to differentiate the materials to determine suitability for functionality.
R11: Shifted from material selection to material justification.

F12: Students were back-loading preliminary / preparatory work on the Impact Tester assignment, pushing the workload to an already congested end of semester, failing to address design issues, and inducing significant stress as a result.
R12: Required students to complete and submit preparatory work in advance of starting the drawings for the Impact Tester.

4.3. Session 2018 Findings & Resolutions

F13: Students understood the value of sketching in engineering but lacked confidence in their ability to effectively communicate using hand-drawn graphics.
R13: Sketching was included in the AGC course to demonstrate the value of sketching to convey ideas but was not a core element of the course. As time allows in future sessions, consider incorporating sketching into other assignments.

4.4. Session 2019 Findings & Resolutions

F14: As students encountered and absorbed more aspects of design beyond the traditional Machine Design courses, i.e. the design esoterica, they observed elements of design that they had previously overlooked including design qualities such as aesthetics, part handling safety, stress reduction, etc. As their inventory of mechanical design esoterica expanded, they sought to understand the role of design elements as well as how to incorporate them in future works.
R14: Fostered a sense of curiosity in non-core elements of mechanical design by sourcing and discussing artifacts of both historic and current design. Introduced further industry standards and resources.

5. SCAFFOLDING CONTENT

Some resolutions necessitated the development of scaffolding content to bridge the divide between students' inconsistent baseline knowledge and fully evolved design thinking, encompassing core and esoteric design elements. Following are descriptions of some scaffolding content.

5.1. Drawing Views Tutorial

An assembly drawing of a centrifugal governor for a steam engine was provided to illustrate the functionality of the clevis yoke. Multiple axonometric views show all external features on the yoke. Students identify the features (sometimes in aggregate) and what type(s) of views may communicate each feature's location, orientation, and geometries for the feature(s). They identify which feature(s) can be incorporated into a single view and subsequently organize the initial drawing views layout.

5.2. Projection Angle & Orthographic Views

Two six-sided boxes, each face with a window containing an image of the projection angle view being represented, are used to show the relationship between view placement and artifact, in this case a model of a child's stuffed bear, Fig. 5. The sides interlock using magnets, which allows them to be disassembled and reorganized to validate the student's understanding of the view placement for first- and third-angle projection.

5.3. Material Selection

Students are provided with a material selection, including grade and treatment where appropriate, for each workpiece. They must understand the functionality of the workpiece, including relative motions and loads, operating conditions, handling, etc. Using Machinery's Handbook® and specified suppliers for specialty materials, they must justify the use of the indicated material and treatment in comparison to other materials, grades, and treatments.

5.4. Surface Finish Module

Students accessed a PowerPoint® presentation which explained how to specify surface finishes, and referenced a collection of industry surface finish comparators, including Fowler® and Charmilles® surface roughness standards in the instructor's collection. They were shown how to comparatively determine the finish on a physical artifact. Based on the determined functionality and interactions of each feature on their assignment workpiece(s), students selected an appropriate surface finish specification that was both functional and economical.

5.5. Limits & Fits Module

Using ANSI fit classes information in Machinery's Handbook® for reference, students progressed individually through a PowerPoint® presentation which explored the terminologies associated with Limits and Fits tolerance selection. Graphics demonstrated the meaning of each fit class, and sample exercises showed how to calculate the appropriate tolerance for non-standard nominal sizes. Unfortunately, no documentation was found for using Limits & Fits in a GD&T application. Content was developed to demonstrate how to use ANSI fit classes with GD&T. Students used this knowledge in their final assignment. Standard samples demonstrating various ANSI fit classes are not available, and the students' physical understanding of fit classes remained a challenge which may be addressed in the future by developing a set of demonstration samples.

6. INDEPENDENT MICRO COURSES EMERGE FROM AGC

As AGC evolved, critical knowledge gaps in the students' foundational knowledge became evident. Understanding of key design elements including manufacturing processes, parts interactions, and the role of surface finishes, were absent. These gaps were the missing *why* elements that bridged the theory of *how* to do something and the *what* you get as outcomes. In this course, specific scaffolding content was provided as tutorials, as independent content, and in discussions with the instructor. The missing content of surface finishes and limits & fits were addressed using instructor-supported modules. Each module used in AGC was essentially an instructor-supported micro-course. To further develop these two particular modules as *independent* micro courses, the content must progress to be self-supporting, and physical samples for each should be incorporated as kits. Though neither trivial nor inconsequential, design esoterica are not taught in conventional engineering design courses. IμCs for design esoterica, developed to be fully independent of instructor support and ideally with physical samples where appropriate, could be incorporated as on-demand learning opportunities in core design courses or called upon by students working on co-curricular engineering teams.

A plan forward has been envisioned for these two elements, but what other design esoterica knowledge would industry like to see available to students? Input from industry, academia, and student stakeholders should be solicited to determine what mechanical design esoterica is important to them, as well as what level of competency therein they would expect. From there, IμCs should be developed and evaluated for effectiveness against the needs of the stakeholders.

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The participation, feedback and support for the course by early AGC students has improved it for those that follow. I hope that their transition into industry was made easier by AGC.

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References

[1] Jeff Barrie, "Same, same but different: core design teaching in mechanical engineering," in International Conference on Engineering and Product Design Education. London, United Kingdom, 6-7 September 2018, pp.38-43. London: EPDE.

[2] Syd Pace, "Mechanical acumen for novice product designers: a teaching methodology," Int. J. Mech. Eng. Educ. 2012, 36/1: 1-15.

[3] Ken Ferens, Marcia Friesen, "An industry focus group forum for the assessment of new engineering graduates," in International Conference on Frontiers in Education: Computer Science and Computer Engineering, Las Vegas, 2011: pp.1-7.

[4] Marjaneh Issapour, and Keith Sheppard, "Evolution of American engineering education," in American Society for Engineering Education, 2015 Conference for Industry and Education Collaboration, 2015, Session ETD-315: 1-24, Washington DC: ASEE.

[5] Jennifer Case, "The historical evolution of engineering degrees: competing stakeholders, contestation over ideas, and coherence across national borders," in Eur. J. of Eng. Educ. 2016; 42(6): 974-986. DOI 10.1080/03043797.2016.1238446.

[6] Mir Atiqullah, Aaron Cowin, Ed Ising, et al, "Development of a sophomore manufacturing laboratory course to streamline the manufacturing education within mechanical engineering curriculum," in: Proceedings of IMECE04, Anaheim, CA, 13-20 November 2004, paper no. IMECE2004-61935, pp.259-267. New York: ASME.

[7] Ashley Ruocco, Sophoria Westmoreland, Linda Schmidt, "Sketching in design: easily influencing behavior," in Proceedings of IDETC/CIE 2009, San Diego, CA, 30 August – 2 September 2009, paper no. DETC2009-87503, pp.1249-1257. New York: ASME.

[8] Andy Zhang, "Teaching computer aided product design with aesthetic considerations," in Proceedings of IDETC/CIE 2005, Long Beach, CA, 24-28 September 2005, paper no. DETC2005-85531, pp.581-584. New York: ASME.

[9] Ken Ferens, "External assessment of engineering programs," in Proceedings 2012 Canadian Engineering Education Association Conference, Winnipeg, MB, 17-20 June 2012, paper no. CEEA12-080, pp.290-293. Winnipeg: CEEA.

[10] Alokesh Pramanik, and M. Nazrulo Islam, "Module-based teaching of mechanical design. Chapter 5," in Using technology tools to innovate assessment, reporting, and teaching practices in engineering education. Hershey, PA: IGI Global, 2014, pp.60-68. DOI: 10.4018/978-1-4666-5011-4.ch005.

[11] Jim Sykes, Private communications; email between Jim Sykes & Kyle Lenton. 30 September 2015.

[12] Jim Sykes, Recollections of informal conversations. 2005-2015.