USING META-CASES FOR CAPSTONE LEARNING

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Abstract -*The purpose of capstone courses and projects in engineering is to provide a learning experience that effectively and reliably solidifies earlier acquired understandings. It provides a culminating exercise that lies just beyond a student's existing ability so that learning is furthered while motivation is preserved. Historically, individual engineering projects, practicums, and internships have been heavily used to provide that culminating experience; however, with often disappointing results. This has been particularly the case in attempting to cap off programs in systems engineering where the learning ideal would be to have a student experience a real-world complex multi-disciplinary engineering and program environment.*

Given the limitation, this paper proposes using a term-long, class-based, repeatable meta-case as the capstone learning venue, particularly in support of systems engineering programs where securing meaningful experiential learning is difficult. Case teaching is a classic approach in law, medicine and business faculties where the need to develop higher cognitive abilities—analyzing, synthesizing and judging—inside high ambiguity and across multi-disciplines is paramount. A meta-case, as opposed to other case types, is characterized by the use of a very complex, multi-factor (engineering) real-world challenge with a long, multi-stage solution scenario. In proposing the use of a capstone meta-case, the paper presents its use in an aerospace systems engineering environment where development timelines are very long, and where the engineering requirements and solutions are many and highly interdependent. It specifically discusses the course design structure and considerations associated with a meta-case based on the development of the Airbus A400 military transport aircraft. The paper is based on a year-long study into the use of the case method for teaching aerospace systems engineering.

Keywords: Engineering education, capstone course, case method, meta-case, systems engineering, aerospace engineering, Airbus A400M

1. INTRODUCTION

The purpose of capstone courses and projects in engineering is to provide a learning experience that effectively and reliably solidifies and, ideally, furthers earlier acquired understandings. Historically, individual engineering projects, practicums, and internships have been heavily relied upon to provide that culminating experience; however, with often disappointing results. This has been particularly the case in attempting to cap off programs in systems engineering (SE). In SE, the capstone ideal would be to have a student immersed in a real-world, complex multi-discipline engineering and program management environment; however, those immersive opportunities are scarce.

Given the limitation, this paper proposes using a term-long, class-based, repeatable meta-case as the capstone learning venue, particularly in support of SE programs where securing meaningful experiential learning is difficult. Case teaching is a classic approach in law, medicine and business faculties where the need to develop higher cognitive abilities—analyzing, synthesizing and judging—inside high ambiguity and across multi-disciplines is paramount. A meta-case, as opposed to other case types, is characterized by the use of a very complex, multi-factor (engineering) real-world challenge with a long, multi-stage solution scenario. In proposing the use of a capstone meta-case, this paper firstly addresses the merits of using the case method in general, and then explores the why and how of using a meta-case in an engineering environment, particularly in an SE environment.

This paper is based on a year-long exploration into the possible use of the case method for teaching aerospace systems engineering at the University of Manitoba. The recommended capstone approach has been derived firstly through the review of pertinent adult learner concepts and practices, with particular attention given to the findings of 2009-2012 multi-participant study done to identify a graduate reference or baseline curriculum for SE.[1] Supporting the baseline literature review, exploration further included the extensive use of the case method in an actual course—OPM 4620 Aerospace Life-Cycle Management—and in the preliminary development of a term-long capstone course based on a single meta-case—the Airbus development of the A400M Atlas military transport aircraft. The capstone course is currently pending final detail development and first delivery.

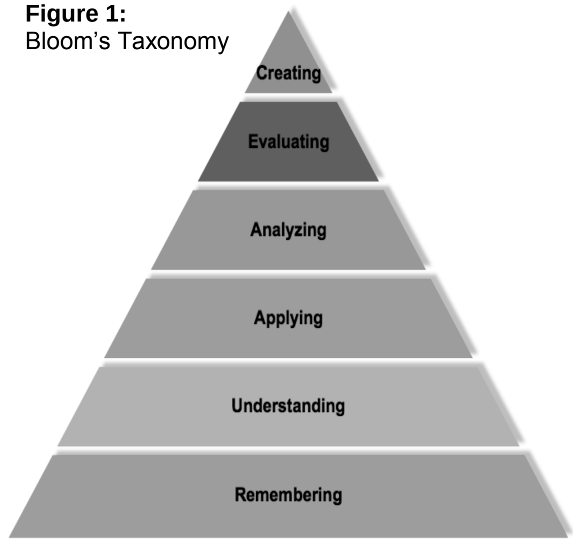
2. THE CASE INSTRUCTION ARGUMENT

"Learning is an active process in which the learner constructs meaningful relationships between the new knowledge presented in the instruction and the learner's existing knowledge. A well-designed instructional strategy prompts or motivates the learner to actively make these connections...[2] Historically, individual engineering projects, practicums, and internships have been heavily used to provide that culminating experience; however, the results have been at best mixed and certainly not reliable. That said, the ability to provide a student an experiential event—an applied event—where the student is immersed in a real life scenario is still optimal.[3] The question is how to create an optimal learning environment that is effective, efficient, and reliable, and one that ensures "the challenges presented lie just beyond one's competence so that motivation is preserved as new challenges are tackled"[4]

Beyond creating a stimulating, repeatable learning condition, an SE capstone course, to be most effective, must take into account the following:

- **Abstract Multi-dimensional Subject Matter**—SE is an engineering discipline particularly focused on managing multi-dimensional challenges and trade-offs inherent in undertaking the development of highly complex systems such as an aircraft. The course, as a capstone, must reveal and reinforce the higher level abstraction and complexity of that problem space;
- **Higher Order Learning Objectives**—inherent in the purpose of a capstone experience is the need to exercise a learner's higher order critical thinking abilities—*analyzing, evaluating and creating*—as per Bloom's Learning Taxonomy (see Figure 1);

Figure 1:
Bloom's Taxonomy



- **Transformational Learning Need**—the capstone student body, anticipated to be made up of young motivated individuals will have already formed solid world views or schemas, schemas that have been significantly shaped by their junior and tightly focused engineering experiences. The capstone course must be designed in a way to readily allow students to recognize, accept and accommodate new system understandings and appreciations. Namely, the course needs to be transformational for the students.[5] It must allow students the opportunity to critically examine evidence, arguments, and alternate points of view, and allow them to validate how and what they understand; and,
- **Time and Resource Constraints**—unlike other engineering domains, where lab work and, or practicums can be effectively used to demonstrate and exercise understandings, that is less the case for SE, particularly, where you want to demonstrate and synthesize a broad spectrum of abstractions as in a capstone course. Real-world SE scenarios can tie up large scale resources across many years, a reality that can't be affordably or realistically fully replicated in a capstone course. However, the course must seek to create the learning conditions and context "so that time is effectively compressed and the learning process of an SE is significantly accelerated as compared to the rate at which learning would occur naturally on the job.[6]

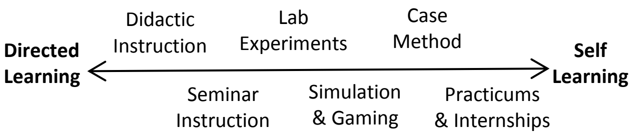
As depicted in Figure 2, instructional approaches can be perceived as sitting along a continuum from being externally-directed to self-directed, with individual

[1] BKCase. Guide to Systems Engineering Body of Knowledge (SEBoK) and the Graduate Reference Curriculum for Systems Engineering (GRCSE) found at bkcase.org.
[2] Gary Morrison et al., *Designing Effective Instruction, 4th Ed*. (New Jersey: Wiley, 2004), 150.
[3] Richard Sugarman et al., "Development of a Systems Engineering Course for Multiple Delivery Methods" (paper presented at 121st ASEE Annual Conference & Exposition, June 15-18, 2014).
[4] Alice Squires et al., "Investigating an Innovative Approach for Developing Systems Engineering Curriculum: The Systems Engineering Experience Accelerator" (Conference paper, American Society for Engineering Education. AC 2011-1295).

[5] Ibid.
[6] Ibid.

instructional options advantageous for differing learning conditions and wanted outcomes.

Figure 2: Instructional Options



Given the specific capstone learning considerations noted above, the more favourable approaches are towards the self-directed, but not fully self-directed. While didactic teaching—the traditional classroom instruction—remains a mainstay for teaching at the undergraduate level, it is not very effective in addressing Bloom's higher order learning categories. While the more participatory seminar and lab formats are better options, they ultimately also fall somewhat short as they fail to sufficiently immerse the learner in a real problem-space as a participant. However, if you go too far towards fully immersed self-directed—the on-job practicum or internship—where the learning can at times be the most beneficial, the cost (time and money) as well as unreliability, unfortunately rises significantly. As Paul Ramsden notes,

> *The cardinal difficulty with practicals, apart from their expense,…is [it is] taken for granted that students will learn if they do things… But doing things does not imply understanding the processes of inquiry or relating practice to theoretical knowledge. Just as it is possible to reproduce ideas and facts without understanding them, so it is possible to learn how to do things without understanding the reasons for doing them.*[7]

Accordingly, one is arguably left with selecting from between a simulated or an actual case learning venue, with both having their strengths. Simulation—be it a table-top exercise or a computer generated simulation—does permit reliable repeatability and does readily demonstrate formula-type relationships, but does lack some real-world legitimacy, particularly in a human behaviour context. The case study, alternatively, doesn't have the same level of repeatability or in-scenario engagement, but they are extremely helpful in developing critical thinking skills and they enjoy significant real-world legitimacy as they are based on actual historic events and circumstances. It is the legitimacy aspect that is particularly important if seeking to encourage transformational understanding as in the case of a capstone SE course. Hence, given the wanted transformational quality, the in-class case study approach is recommended; specifically a meta-case study.

3. THE META-CASE ARGUMENT

As noted at the outset, the case method of instruction is widely used in law, medicine and business faculties where the need to develop critical thinking abilities inside high ambiguity is paramount, as it is in SE. As detailed in Table 1, case instruction is appropriate "when the lesson objectives include analyzing, synthesizing, and judging" as well as "involve higher cognition skills and affective development."[8]

Table 1: Case Study Learning Attributes[9]

Case studies have proved effective in developing the following skills
Analysis and critical thinking
Decision making
Judging between different courses of action
Handling assumptions and inferences
Presenting a point of view
Listening to and understanding others
Relating theory to practice

Case studies, based on actual situations, provide a scenario in which students must go through the process of analysis and development of recommendations. However, a case study provides more. It provides a structured way to live and learn through an actual organizational experience, validating classroom concepts and one's own understandings. That is, it provides the opportunity for learning through the actual experiences and mistakes of others as noted below:

> *Case studies are a classic approach to providing experience-based learning. A case study can be used to illustrate successes, failures and underlying causes to both… The case studies use a story-based approach relying on extensive interviews with a number of key individuals in each case to provide multiple, interwoven perspectives on project successes and shortcomings.*[10]

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[7] Paul Ramsden, *Learning to Teach in Higher Education, 2nd Ed.* (London: RoutledgeFalmer, 2007), 155-156.

[8] Glenn Johnson, *First Steps to Excellence in College Teaching, 3rd Ed.* (Madison USA: Magna Pub., 1995), 83.

[9] John Heath, *Teaching and Writing Case Studies, 2nd Ed.* (Bedfordshire UK: The European Case Clearing House, 2002), 12.

[10] Alice Squires et al., "Investigating an Innovative Approach for Developing Systems Engineering Curriculum: The Systems Engineering

Cases are not all the same, however. There is a case hierarchy, as delineated in Table2, which is based on increasing situation complexity—numbers of factors, actors and alternatives—as well as solution complexity. In considering the needs of an SE capstone course, it is the use of a meta-case, the most demanding of case types, that is envisioned—a meta-case that follows a technology development from requirements determination to first delivery.

Table 2: Case Study Typology[11]

Problem	• Short and specific • Focuses on solutions • Used frequently in teaching • Encourages linkage to theory or experience
Event	• Provides some detail around a specific event • Real or constructed • Intended to bring out solutions or lessons learned
Full Scenario	• Complex story • Multiple layers • Greater ambiguity • Requires complex response • Conclusions can be more ambiguous
Complex Scenario	• Longer and more complex • Greater number of variables • Conclusions and lessons derived are highly contextual
Meta-Case	• Designed to bring together experience and history of complex [program] or management issues • Takes a longer term perspective • Full [development] history • Focuses on knowledge background transfer

As proposed for capstone purposes, "[m]eta-cases typically present a complex problem from a longitudinal perspective, exploring how the problem has evolved over time."[12] A meta-case write-up is, by definition, made up of an extended upper system or organization storyline, like the development of an aircraft, and multiple embedded and inter-connected critical decision-point scenarios for focused discussion.

Further, the meta-case should be as accurate as possible in recounting the actual technology development story. The case method, in general, doesn't explicitly require that a case write-up always fully follow an actual or true story. However, for an SE capstone course, it is considered essential. To allow for observational learning—learning through others—to occur, as well as to use the case to validate SE concepts and practices through example, it is considered that an actual historical case, with no deviations from the actual upper level storyline, be used.

Arguably, an historical recount offers the only extensive evidential base for the analysis and contemplation of a major multi-year development. "However professionally skeptical we may be about learning from the past, there is no doubt that we try to do it all the time. Historical analogies, comparisons, and metaphors are all around us; they are a source of collective wisdom on which we must rely. It is unlikely that we could live without them even if we wanted to."[13] Ultimately, what is required for an SE capstone course, and accordingly advocated, is a detailed, multi-element meta-case that accurately recounts a recent development of a large-scale development; a development that readily reveals all the SE processes, trade-offs and challenges inherent in such an endeavour.

That all said, if the meta-case is well crafted, it does not prohibit students and individual class discussions from exploring alternative solutions to the embedded problem/decision scenarios presented. The meta-case, again, if well crafted, can facilitate real-world observation, in-class solution exploration, and individual learning to simultaneously occur at three abstraction levels:

- **the Program Management Level**—i.e., at engineering-business management interface;
- **the Team Dynamics Level**—i.e., within a multi-discipline SE decision environment;
- **the Individual Skills Level**—i.e., in the employment of specific SE concepts and practices.

It is this potential for three-level learning to simultaneously occur that ultimately argues for the use of meta-cases for SE capstone learning; meta-cases based on a real-world technology developments. A journey through a meta-case can provide a student his or her first holistic look at a system's development. That said, it is all dependent on a well-crafted case.

4. CRAFTING CAPSTONE META-CASES

To further understand the potential and challenges of using the case method for capstone learning, the case method was employed in the fall 2015 in delivering an advanced systems course—OPM 4620 Aerospace Life-Cycle Management. The course relied on a selection of dissociated short aerospace design and manufacturing case studies throughout to explore and exercise key SE

Experience Accelerator" (Conference paper, American Society for Engineering Education. AC 2011-1295)

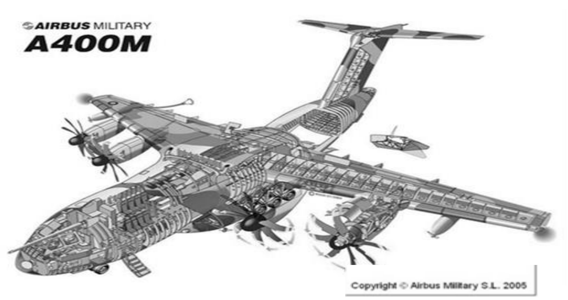
[11] Andrew Graham, *Making the Case: Using Case Studies for Teaching and Knowledge Management in Public Administration* (Kingston: McGill-Queen's Press, 2011), 14.

[12] Ibid., 30.

[13] James Sheehan, "How Do We Learn from History?" *Perspectives on History*, January 2005, American Historical Association, accessed May 17, 2015, www.historians.org/publications-and-directives/perspectives-on-history/January 2005/how-do-we

concepts and skills. Cases were well received, generating heightened engagement and discussion across the classroom. Alongside the delivery OPM 4620, a more ambitious initiative was undertaken to craft an actual capstone course based on a single comprehensive meta-case. The technology development selected was the recent development of the Airbus A400M Atlas aircraft (reference Figure 3). While detail session planning and initial delivery of the capstone course is still pending, the lessons learned thus far from both initiatives are many.

Figure 3: Airbus A400M Program Overview[14]



The A400M Atlas, with its origins dating back to the 1980s, is a four engine turboprop military transport aircraft built by Airbus in its final assembly plant in Seville Spain. It was designed to be a tactical airlifter with strategic capabilities as well as air-to-air refuelling. "Powered by four unique counter-rotating Europrop International (EPI) TP400 turboprop powerplants, the A400M offers a wide flight envelope in terms of both speed and altitude." After over ten years of development, the aircraft's maiden flight took place in 2009. Undergoing flight testing thereafter, the aircraft received flight certification and initial operating capability (IOC) in 2013, with the program's first aircraft delivery to France also taking place in that year.

In any industry environment there are arguably a host of possible system development cases that can be used for case purposes and, certainly, specific industry drivers and imperatives to be considered. That said, and certainly was the case when searching for an aerospace case, certain general case selection criteria should be considered when selecting a specific technology development for a meta-case. A good SE meta-case ideally will have:

- relevance and applicability to current design and manufacturing practices;
- a demanding complex set of (interdisciplinary) requirements and design challenges;
- a challenging multi-participant supply chain and, or end-user environment;
- a clean-sheet straight-line development which readily permits storey compartmentalization of the progressive transformation of an identified user requirement into an actual operating system;
- sufficient technology development source material (i.e., the storyline) through accessible industry publications and participant interviews and documents; and
- expected heightened student interest.

The meta-case, by its definition, has a long overarching storyline which is made-up of a sequence of issues and/or decision-points along the way. That storyline can potentially be captured through open source industry and company publications and documents. The meta-case write-up does not need sensitive firm specific design or manufacturing trade secrets to be suitable; the case write-up needs only to describe the critical design and manufacturing decision-points and broad challenges therein to be effective. It is in the sequential exploration of the critical development decision-points that the course architecture is based, not the detailed decisions and actions taken by the firm thereafter. This is not to say that having the inside detailed story as to how a decision was ultimately handled by the firm isn't beneficial for teaching the case, but it is far less vital than being able to adequately describe the upfront problem space—a problem space to which the students themselves, within their expertise, will make decision recommendations.

In considering the spectrum of recent aerospace developments—Boeing 787, V22 Osprey, Airbus A380, Lockheed-Martin F-35, etc.—it was concluded, in keeping with the above considerations, that the Airbus A400M Atlas program had the best overall balance of development attributes and information accessibility for an aerospace capstone course. The A400M program, through its clean-sheet straight-line development and its ample design and management challenges, nicely works for exploring an SE's roles and responsibilities in a large complex program. It further readily highlights such aerospace domain design realities as demanding technical requirements, challenging investor and customer demands, tight design-build timelines, demanding quality assurance imperatives, and pressing environmental mitigation considerations**.**

Beyond the careful upfront selection of a suitable meta-case, the follow-on curriculum design is as equally critical to generating a meaningful course experience. Given the meta-case is to support learning through the progressive provision and review of program decision-

[14] Airbus Defence & Space at http://militaryaircraft-airbusds.com/Aircraft/A400M/A400MAbout.aspx

points, it is important that the course design—its weekly unfolding, and how future sessions build-upon previous sessions—makes sense to the student. That is, the student should be able to readily see through the individual session topics and their sequencing, how each session topic is critical in its own right, and how they are collectively linked to make the technology development possible. For illustration, see Table 3 for the tentative A400M weekly topics and how they seek to follow the overarching development storyline. A meta-case course as proposed can be conducted over one or two terms with deeper case exploration and skills development possible with the longer timeline.

Table 3: A400M Capstone Course Schedule

Week	Description
Part One: Settling on the Requirements	
Week 1	Opportunity Identified (1982-1989)
Week 2	Stakeholder Requirements (1989-1995)
Week 3	The Wing Design Decision (1995-1997)
Part Two: Trade Offs and Concept Selection	
Week 4	Airlifter Competition & Selection (1997-1999)
Week 5	Contract Negotiation & Engine Selection (2000-2003)
Part Three: Concurrent Design-Build, and Configuration Control	
Week 6	Detail Design & Data Management (2003-2005)
Week 7	Setting Up an Integrated Supply Chain (2005-2006)
Week 8	Initial Sub-Assembly (2006-2007)
Week 9	Final Assembly & First Build (2008-2009)
Part Four: Airworthiness and System Validation	
Week 10	Airworthiness & First Flight (2009-2010)
Week 11	Full Production Decision (2009-2010)
Week 12	First Delivery & Follow-on Support
Week 13	Lessons Learned

As was exercised in delivering OPM 4620, and as is envisioned in delivering the A400M meta-case, each session would require students to firstly review on their own provided weekly case and supporting readings, as well as develop initial responses to the week's task(s) or assignment(s). Following that individual preparation, students would be required to work in small groups to formulate their final response(s) to the assigned task(s). The course inclusion of group activity is considered essential in seeking to better mimic an actual program development environment. Assigned tasks can vary from providing a substantiated program recommendation to developing an SE deliverable like a Systems Engineering Master Plan (SEMP). After group responses have been generated, the case elements and the group responses are discussed in large forum, as is the actual firm response to the situation. Overarching and, or protracted individual and group assignments can also be used to further learning and aid grading.

In short, the understood ideal is to craft a case and a supporting course curriculum that doesn't only further individual (SE) engineering skills, but also exercises engineering teamwork and problem-solving, while revealing overarching managerial imperatives and dynamics.

5. CONCLUSION

As noted at the outset, the purpose of a capstone course is to provide a culminating learning experience for engineering students completing their studies, and, in the case of this paper, their aerospace SE concentration. It is an experience that not only needs to solidify earlier acquired engineering understandings, but also further stretch them. The aim of this paper was to propose and explore the use of meta-cases to provide that culminating experience, and, to that end, it has done its job. Understanding gained to date indicates that a carefully crafted course employing a real-world based meta-case can provide a powerful capstone learning experience.

It should be noted that the paper does fail to address two lingering questions—is the meta-case approach as applicable to other engineering disciplines as it is to SE, and are the benefits identified worth the case and course development costs? To both questions, arguably, the answer ultimately rests with the reader; however, two concluding observations are shared.

First, engineering, regardless of specific discipline and related industries, is executed in complex contextual environments composed of competing individual and institutional interests, values, beliefs, ways and means. Case instruction, over the other capstone venues, promises a more reliable, repeatable way to raise student understanding of those greater contextual interplays, while still retaining focus on the engineering task(s) at hand.

Second, and finally, while it is hard not to conclude that the upfront cost of developing a capstone course based on a meta-case is significant. Certainly the experiences gained from delivering OPM 4620 and developing the A400M meta-case support that conclusion. However, the benefits, beyond those already noted in terms of developing individual students, are potentially also significant. Once created, a meta-case and supporting course, which is likely employable for three to five years, firstly promises to relieve a sponsoring unit from the annual exercise of finding and supervising often problematic individual capstone projects and, or practicums. Beyond that, the necessary research required in developing and publishing a meta-case, offers the author, and his or her institution, the opportunity to establish broader and more lasting connections, dialogues and visibilities with a targeted company and, or industry. All said, the potential long-term return-on-investment can be well worth the upfront costs.

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