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Quantifying the Ability of the Digital Engineering Factory to Address the Digital Engineering Competency Framework

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Abstract

It has been argued that higher education environments around the world have a responsibility to reevaluate their role in the education of future engineers as the engineering discipline undergoes significant change. The Digital Engineering Factory (DEF) is being developed by the University of Arizona (UA) to support the latest developments in digital engineering. The DEF is a collaborative digital engineering environment at the heart of the engineering curriculum. It comprises a tool suite that spans multiple engineering disciplines, thus supporting multiple courses across the Department of Systems and Industrial Engineering (SIE), which houses the systems engineering, industrial engineering, engineering management, and software engineering (SFWE) programs. In this paper, we evaluate the degree to which the DEF has the potential to address the competencies outlined by the System Engineering Research Center (SERC) in their Digital Engineering Competency Framework (DECF). The DECF has been developed to provide the Department of Defense (DoD) with a set of well-defined competencies comprising the knowledge, skills, abilities and behaviors (KSABs) that are required of the digital engineering workforce.

Introduction

It has been argued that higher education environments around the world have a responsibility to reevaluate their role in the education of future engineers as the engineering discipline undergoes significant change[1]. Digital Engineering (DE) is “an integrated digital approach that uses authoritative sources of systems’ data and models as a continuum across disciplines to support lifecycle activities from concept through disposal. A DE ecosystem is an interconnected infrastructure, environment, and methodology that enables the exchange of digital artifacts from an authoritative source of truth”[2]. One area of DE that has received significant attention in recent years is the digital thread[3]. The digital thread refers to the integration of digital information across the entire lifecycle of a system. This necessarily means that different engineering tools, each supporting some aspect of the system lifecycle, must be integrated in some way as to enable the seamless transfer and utilization of data. Today’s industry leaders consider digital thread initiatives to be a top priority[4].

The Digital Engineering Factory (DEF) is being developed by the University of Arizona (UA) to support the latest developments in digital engineering. The DEF is a collaborative DE environment at the heart of the engineering curriculum[5]. It comprises a tool suite that spans

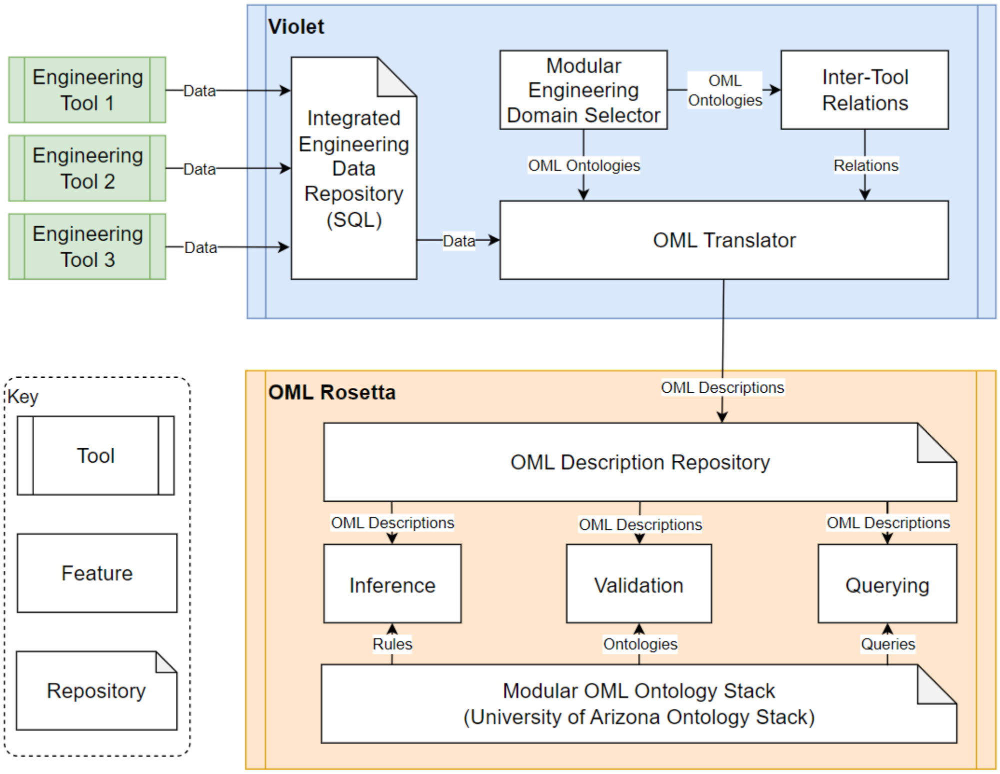
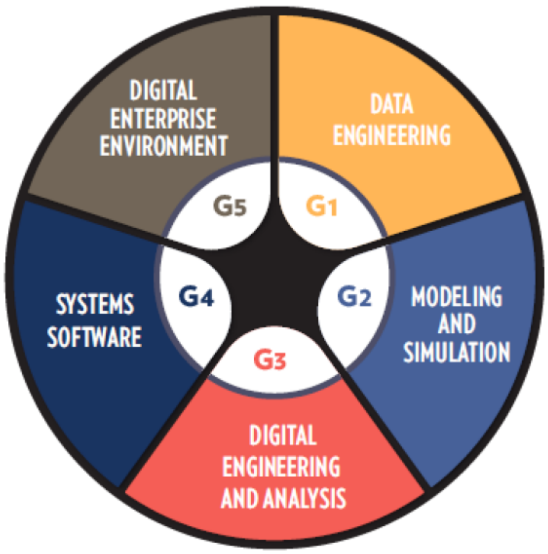


Figure 1: The Digital Engineering Factory (DEF) Architecture

multiple engineering disciplines, thus supporting multiple courses across the Department of Systems and Industrial Engineering (SIE), which houses the systems engineering, industrial engineering, engineering management, and software engineering (SFWE) programs. The DEF employs a hub-and-spoke approach to data integration, with the Violet tool[6] acting as the 'hub'. Violet integrates data from multiple engineering tools into a centralized Structured Query Language (SQL) database. Violet can then generate an Ontological Modeling Language (OML)[7] representation of this dataset that is structured according to the UA Ontology Stack. This enables reasoning and data validation. These capabilities are enabled by the use of OML and other Semantic Web Technologies (SWTs). SWTs provide an approach to the structuring and understanding of data. They have the potential to capture the knowledge and domain-specific concepts necessary for understanding and analyzing complex systems. SWTs utilize ontologies, reasoners, and query languages to structure existing knowledge, validate knowledge, and infer new knowledge[8]. The DEF has been used to support a notional Rover design exercise[9], perform an orbital analysis of a cubesat[10], and produce a Bayesian network representation of a spacecraft verification strategy[11]. A detailed account of the development of the UA Ontology Stack is provided in[12], and lessons learned during development of the DEF in general are presented in[13]. This architecture is presented in Figure 1.

As we continue to develop the DEF, our goal is to ensure that it will help engineering students to develop DE-relevant skills. The Digital Engineering Competency Framework (DECF) has been developed by the Systems Engineering Research Center (SERC)[14]. The purpose of the DECF is to provide the Department of Defense (DoD) with a set of well-defined competencies comprising



FOUNDATIONAL DIGITAL COMPETENCIES	
F1	Digital Literacy
F2	Digital Engineering Value Proposition
F3	DoD Policy/Guidance
F4	Coaching and Mentoring
F5	Decision Making
F6	Software Literacy

LEGEND:
C# - Competency Title
F# - Foundational Competency Title
G# - Competency Group
S# - Competency Subgroup

G1 DATA ENGINEERING			
S1	Data Engineering	C1	Data Governance
		C2	Data Management

G2 MODELING AND SIMULATION			
S2	Modeling and Simulation	C3	Modeling
		C4	Simulation
		C5	Artificial Intelligence/Machine Learning
		C6	Data Visualization
		C7	Data Analytics

G3 DIGITAL ENGINEERING AND ANALYSIS			
S3	Digital Systems Engineering	C8	Digital Architecting
		C9	Digital Requirements Modeling
		C10	Digital Validation and Verification
		C11	Model-Based Systems Engineering Processes
S4	Engineering Management	C12	Digital Model-Based Reviews
		C13	Project and Program Management
		C14	Organizational Development
		C15	Digital Engineering Policy and Guidance
		C16	Configuration Management

G4 SYSTEMS SOFTWARE			
S5	Systems Software	C17	Software Construction
		C18	Software Engineering

G5 DIGITAL ENTERPRISE ENVIRONMENT			
S6	Digital Enterprise Environment Development	C19	Digital Environment Development
S7	Digital Enterprise Environment Management	C20	Management
		C21	Communications
		C22	Planning
S8	Digital Enterprise Environment Operations and Support	C23	Digital Environment Operations
		C24	Digital Environment Support
S9	Digital Enterprise Environment Security	C25	Digital Environment Security

Figure 2: Overview of the DECF - reproduced from [14]

the knowledge, skills, abilities and behaviors (KSABs) that are required of the digital engineering workforce. According to SERC, Phase 2 of this research "focused on mapping existing DoD DE training resources against the DECF to identify gaps and provide recommendations on how to build the digital engineering competency of the DoD workforce"[14]. This research effort helped to identify further competencies that have been included in the latest version of the DECF. In this paper, we apply this same approach to evaluate the degree to which the DEF (or any other DE environment integrated within an engineering curriculum) has the potential to address the competencies outlined by SERC.

Methodology

The DECF defines 1228 KSABs across five competency groups and one foundation of general digital competencies. Across these six groups, a total of 31 competencies are defined. This structure is presented in Figure 2. The five main competency groups are summarized in Table 1, reproduced from[14].

Table 1: Descriptions of DECF v. 1.1 Competency Groups, reproduced from[14]

ID	Competency Group	Competency Description
G1	Data Engineering	Apply knowledge on how to acquire, curate, compress, secure, and prepare data resulting from a DE environment. Create or support data-focused processes. Data could originate from modeling and simulation, or from sensors in the physical world.
G2	Modeling and Simulation	Use of digital models to describe and understand phenomena of interest from initiation of the effort through the entire life cycle maturation. Model literacy—understanding what models are and how they work—is required to move into more advanced skills, from the ability to build a model using appropriate tools, standards, and ontology to creating a modeling environment.
G3	Digital Engineering and Analysis	Apply traditional engineering methods and processes in a digital environment. Create new engineering processes and methods for a digital environment. Create digital artifacts throughout the project or system lifecycle. Use engineering methods, processes, and tools to support the engineering and system lifecycle.
G4	Systems Software	Apply technical knowledge in various software or coding languages to create, support, and maintain applications. This includes the abilities to understand, apply, problem solve, create, and critique software in pursuit of particular learning and professional goals.
G5	Digital Environment Enterprise	Use the foundations of data, modeling, and software to create and maintain the digital enterprise. This requires creating the environment in which digital engineers, discipline and domain engineers, program managers, and decision-makers work.

Each of the 31 competencies within these groups and the foundation of general competencies group contain multiple KSABs. In compliance with DoD Instruction 1400.25, each of these competencies is broken down into KSABs relevant to proficiency levels within each competency[14]. These proficency levels are *Awareness, Basic, Intermediate, Advanced, Expert*. An example of a KSAB in competency group G1 (Data Engineering), under competency C1 (Data Governance), at a *basic* level of proficiency, is as follows:

- G1-C1-Basic-6: "Understand and apply principles of usability and accessibility to published information"

To evaluate the degree to which a DE environment could address these competencies, each of the KSABs defined in the DECF was reviewed and a determination was made regarding whether they had the *potential* to be achieved within a Bachelor of Science (BS) program. This process was performed by co-author Alejandro Salado - associate professor of systems engineering with the Department of SIE at the University of Arizona. Note that we are not reviewing whether the DEF or the UA engineering curriculum currently meets the competency requirement, but rather whether a future implementation of the DEF has the potential to. In this way, we identify which competencies could be achieved by a DE environment integrated alongside an engineering curriculum, and highlight requirements for the future development of the DEF.

Results

In this section, we present the results of the evaluation. We believe that an integrated DE environment that has been designed to support an engineering curriculum has the potential to address 382 of the 1228 KSABs (31.1%) defined. Unsurprisingly, as such an environment would be developed to support students up to BS-level, we estimate that only 4.2% of KSABs at the *advanced* or *expert* level of proficiency would be addressed. We estimate that 75.6% of the KSABs at proficiency level *awareness* or *basic* have the potential to be addressed by an integrated DE environment. The results are summarized by competency in Table 2.

We can break down this analysis by competency group. Figure 3 shows the percentage of KSABs that could be addressed by the DEF for each competency group. It also includes a separate measurement that applies to the *awareness*, *basic*, and *intermediate* proficiency levels only. This measurement has been included as it would not realistically be expected that students would complete their BS degree with a proficiency level of *expert* or *advanced*. The analysis suggests that the DEF has the potential to address 87.1% of KSABs related to data engineering up to and including the *intermediate* level of proficiency. It also suggests that the DEF could address 75.9% of KSABs related to modeling and simulation, and 78.1% of KSABs related to digital engineering and analysis, up to the *intermediate* level of proficiency. Such an environment would not, however, have the potential to address systems software competencies. None of the identified KSABs for this competency group were identified as potentially being addressed by a DE environment. Only 24.4% of KSABs related to the digital enterprise environment at a proficiency level of *intermediate* or lower have the potential to be addressed.

We can also review the potential of the DEF to address the KSABs across the different proficiency levels. In Figure 4, we present this information. At the *awareness* and *basic* proficiency levels, the analysis suggests that the DEF has the potential to address 100% of KSABs

Table 2: Summary of KSABs in the DECF and whether they can be addressed by a DE environment
Aw = Awareness; Ba=Basic; In=Intermediate; Ad=Advanced; Ex=Expert

Competency Group	Competency	Total KSABs						KSABs Potentially Addressed By DEF					
		Total	Aw	Ba	In	Ad	Ex	Total	Aw	Ba	In	Ad	Ex
G1	C1	48	3	11	7	14	13	18	3	11	4	0	0
	C2	30	2	7	1	14	6	9	2	7	0	0	0
G2	C3	122	11	25	36	35	15	67	11	23	33	0	0
	C4	56	8	8	16	16	8	35	8	8	14	5	0
	C5	32	2	19	8	3	0	2	2	0	0	0	0
	C6	22	2	4	12	2	2	16	2	4	10	0	0
	C7	47	2	5	12	17	11	14	2	5	7	0	0
G3	C8	55	3	14	18	18	2	43	3	14	15	10	1
	C9	24	1	3	15	4	1	20	1	3	15	1	0
	C10	13	2	2	6	3	0	13	2	2	6	3	0
	C11	106	10	32	17	35	12	58	10	32	13	3	0
	C12	15	2	1	6	5	1	10	2	1	5	2	0
	C13	42	2	18	12	7	3	17	2	10	3	2	0
	C14	18	1	2	1	4	10	0	0	0	0	0	0
	C15	23	1	3	2	7	10	1	0	1	0	0	0
	C16	19	1	3	5	8	2	3	1	1	1	0	0
G4	C17	18	1	8	3	5	1	0	0	0	0	0	0
	C18	47	3	5	5	24	10	0	0	0	0	0	0
G5	C19	47	1	15	3	15	13	12	1	11	0	0	0
	C20	23	2	2	1	10	8	2	1	1	0	0	0
	C21	11	1	2	1	3	4	3	1	2	0	0	0
	C22	11	1	2	2	3	3	0	0	0	0	0	0
	C23	26	3	4	8	9	2	4	2	2	0	0	0
	C24	67	3	6	18	25	15	0	0	0	0	0	0
	C25	42	6	2	7	16	11	1	1	0	0	0	0
F	F1	120	4	16	11	41	48	18	3	12	3	0	0
	F2	12	2	7	3	0	0	12	2	7	3	0	0
	F3	4	3	0	0	0	1	0	0	0	0	0	0
	F4	9	1	1	2	3	2	2	1	1	0	0	0
	F5	29	0	1	5	10	13	2	0	0	2	0	0
	F6	90	7	10	15	38	20	0	0	0	0	0	0

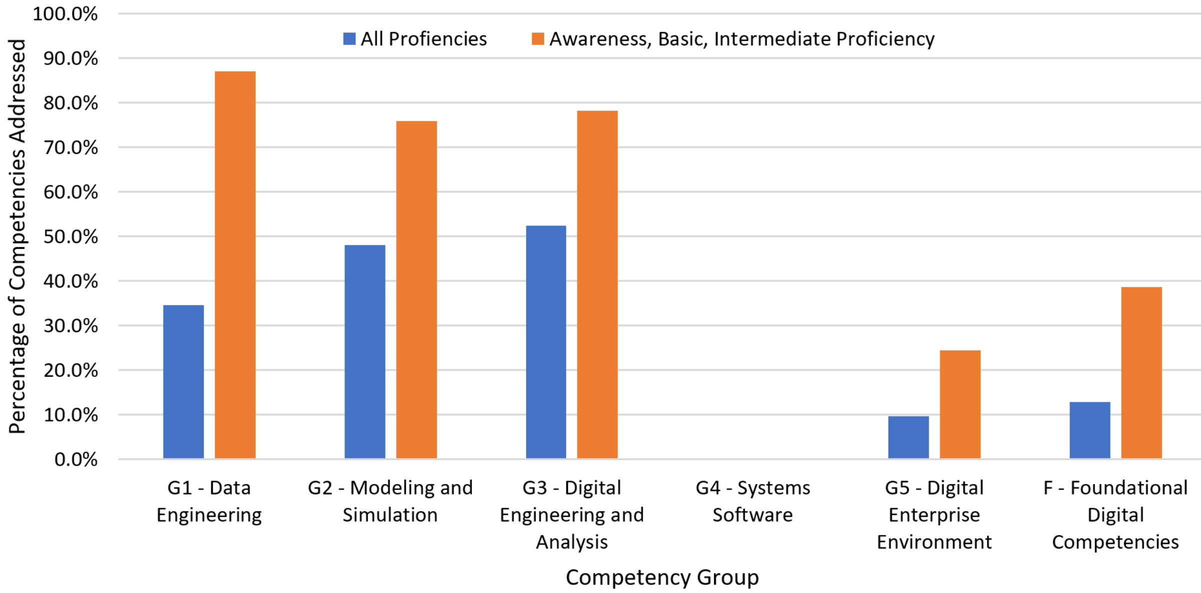


Figure 3: Competencies Addressed by a Digital Engineering Environment Integrated with Engineering Curriculum, Organized by Competency Group

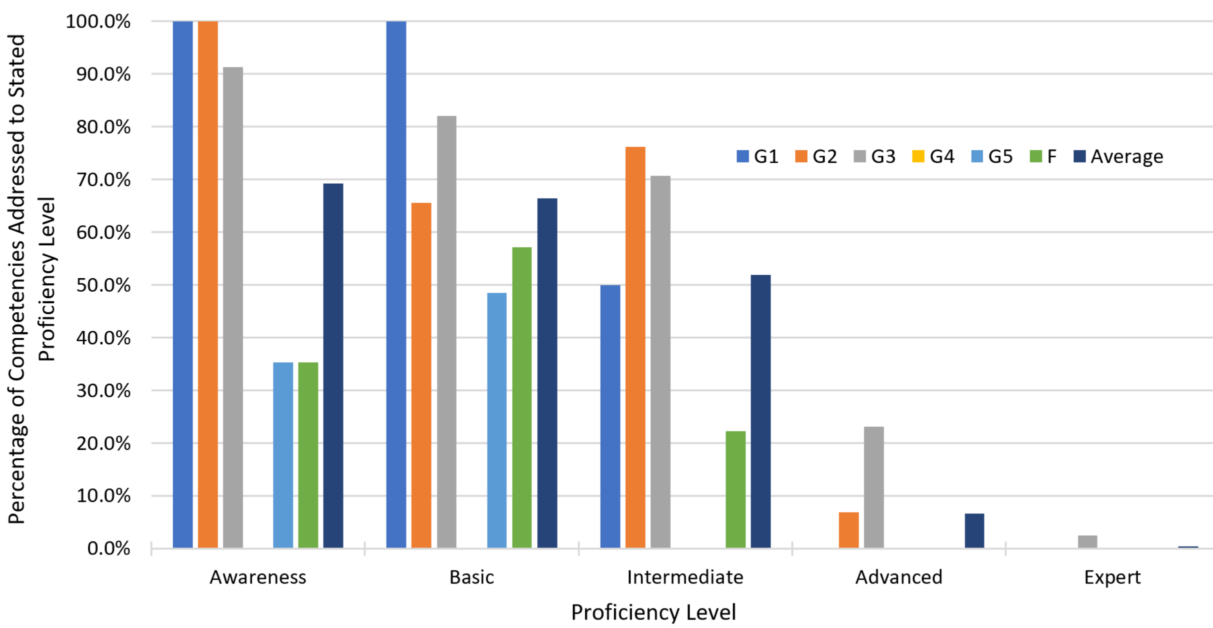


Figure 4: Competencies Addressed by a Digital Engineering Environment Integrated with Engineering Curriculum, Organized by Proficiency

regarding data engineering, and 75.6% of KSABS regarding modeling and simulation. The potential to address competencies associated with digital engineering and analysis is similarly high. With regards to the digital enterprise environment, fewer than 50% of the competencies at proficiency level *basic* or lower have the potential to be addressed, and 0% of those competencies at *intermediate* or higher have the potential to be addressed.

Discussion

In our case, we are developing the DEF to support students at BS level. We are therefore most interested in maximizing the students' competency potential up to and including the *intermediate* level of proficiency. The analysis suggests that the DEF has the potential to offer a significant advantage to students (75% of KSABs or greater) in the following areas:

- Data engineering
- Modeling and simulation
- Digital engineering and analysis

To maximize this value, we should focus on delivering these competency groups during the development of the DEF. Of course, while the competencies associated with the digital enterprise environment may not be particularly well addressed by the DEF, we should consider those competencies that can be addressed as we continue its development.

As stated previously, the purpose of this study has been to quantify the *potential* benefit of introducing an integrated DE environment into an engineering curriculum. We have not considered whether it would be practical to actually realize these capabilities. As we progress through the development of the DEF, it will be important to consider the practical considerations of supporting any particular KSAB, and how it can be realized through specific course content and teaching.

Future work will focus on assessing the DECF competencies with respect to these practical considerations as well, and will ultimately assess which of the DECF competencies have actually been *realized* by the implementation of the DEF.

Conclusion

In this paper, we have reviewed each of the 1228 individual knowledge, skills, abilities and behaviors (KSABs) identified by the Systems Engineering Research Center (SERC) in the Digital Engineering Competency Framework (DECF). We have highlighted which of these KSABs could potentially be addressed by a digital engineering (DE) environment integrated in an engineering curriculum. Our findings indicate that such an environment could significantly address competency groups associated with data engineering, modeling and simulation, and digital engineering and analysis. Such an environment may not significantly address systems software or the digital enterprise environment. As we continue to develop the Digital Engineering Factory (DEF) at the University of Arizona, we will incorporate other considerations into this analysis such as the practicality of addressing the KSABs and, following the deployment of the DEF, a measurement of the actual realization of the KSABs. It is the authors' hope that the developers of similar environments in other academic settings may attempt to quantify the benefits of their deployment using similar analyses as they continue their development.

Acknowledgments

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