ENHANCING FACULTY COMPETENCY IN LEAN THINKING BODIES OF KNOWLEDGE

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Abstract

The Lean Aerospace Initiative's (LAI) Educational Network (EdNet) established in 2002 is comprised of 32 universities who share a common interest to collaborate on developing and deploying curriculum for teaching lean six sigma fundamentals. Supported by a small staff centered at MIT, collaborating faculty have developed a week-long LAI Lean Academy® course, and delivered it to multiple audiences on-campus and in industry and government. The topics of the course map to many CDIO syllabus topics, and the pedagogy and assessment methods have borrowed on the CDIO knowledge base. This paper reports on this undertaking and on the extent to which it has contributed to developing faculty competency for teaching Lean Thinking in engineering and management. Results from this study reveal that instructors have significantly improved their competency to teach Lean Thinking during their affiliation with the LAI EdNet. On average, the instructors' proficiency in twelve Lean Enterprise knowledge areas has increased a full level, from 3.2 to 4.2, on the CDIO Syllabus MIT Activity Based Proficiency Scale. The instructors report that collaboration on conceiving, developing and implementing the curriculum has been the most valuable EdNet activity for increasing their competency.

Keywords: Lean Thinking curriculum, LAI EdNet, LAI Lean Academy® course, CDIO

Introduction

The Lean Aerospace Initiative's (LAI) Educational Network (EdNet) was established in 2002 in response to aerospace industry and government executives' request to develop and deploy curriculum for teaching lean principles at universities, industry and government venues throughout the US. Lean principles are rooted in the Toyota Production System [1] [2], although they are not specific to either automobiles or production. They have been applied in many manufacturing, service and educational organizations, and are being aggressively implemented in aerospace and defense. Over the past decade, these principles have merged with those from Six Sigma [3] and Theory of Constraints [4] and given various names. In this paper they are simply called "Lean Thinking". To be effective, lean thinking should be implemented across a given enterprise leading to a *lean enterprise*, which is "an integrated entity that effectively creates value for its multiple stakeholders by employing lean principles and practices"[5]. The executives felt their new hires, particularly in engineering, were largely ignorant of these principles, and required remedial education.

In responding to the LAI executives' request, the LAI leadership faced multiple challenges:

- Developing and deploying curriculum at a national level in a field with little academic roots, especially in engineering.
- Building faculty competency in a field that is based upon knowledge gained from practice – as contrasted to traditional engineering disciplines that are based upon knowledge from science and mathematics.
- Limited resources

The response to the challenge was to establish the EdNet as a networked based national learning community of academics and industry/government members, and to collectively develop a curriculum called the LAI Lean Academy® course. The strategy was to leverage both financial and knowledge resources to develop competency through collective action. This strategy was based upon four objectives

1. Developing faculty competency in**…**
2. Developing deployable curriculum for**…**
3. Supporting/enabling diffusion into campus courses and degree programs of**…**
4. Assisting LAI members in educating their current workforce to apply and utilize**…**

…Lean Thinking principles and tools.

This paper will focus on the first of these objectives, with some coverage of the second and third. Developing faculty competency is a necessary step to effectively develop and deploy curriculum. Companion papers [6], [7] will describe active learning pedagogies developed and/or used by the collaborating faculty in the LAI Lean Academy curriculum.

Practice Based vs. Science Based Disciplines

Unlike engineering science based disciplines such as structures, dynamics, controls, fluids and thermodynamics, the underlying Body of Knowledge (BoK) for Lean Thinking is not based upon laws of physics and chemistry and is not represented by sophisticated mathematics. The BoK is rooted in processes and people/organizational dynamics for which there are no laws. It relies on understanding "best practices" which are observed through field research of actual enterprises. Best practices are not invariant with time, which means the BoK is subject to change. Much like many engineering science disciplines, information technology is big factor in the current evolution of the BoK.

The above observations apply to many of the CDIO areas of interest, and it takes a fundamental shift in the engineer's mindset to effectively address curriculum design and deployment. Some of the challenges faculty may face include:

1. Establishing competency that can only come through some effective encounter with industry and government practices. Actual work experience is best, but is often in conflict with tenure demands.
2. Gaining access to industry and government "data". The "laboratory" for this field is the real world, not square footage on campus.

3. Realizing that this field is one where knowledge comes more from observation and codification, than from modeling and symbolic manipulation.
4. Devising pedagogies that support a quite different knowledge domain. This includes developing learning strategies and assessment techniques.
5. Limited investment at a national level, compared to engineering science.

Fortunately, the Lean Aerospace Initiative provides a unique resource to faculty for addressing some of these challenges. Its Educational Network has leveraged these and provided additional resources to address them, although item 5 remains a barrier.

Lean Aerospace Initiative Education Network

One of the biggest challenges faced in responding to the aerospace executive's request was lack of financial resources. Although the directive to develop and deploy Lean Thinking curriculum came from "the top", it came without added funds. So a "bottoms up" approach was taken to leverage distributed resources. The backing of the executives did provide some especially valuable resources, however. One was access to industry and government experts and knowledge through the Lean Aerospace Initiative. Another was "customer pull" to academia to attract their interest. And a third was venues for rapidly testing the curriculum and building a cadre of instructors.

Lean Aerospace Initiative

EdNet is part of the Lean Aerospace Initiative consortium of aerospace industry and government members centered in MIT's Engineering Systems Division. "The Initiative's stated mission is to research, develop, and promulgate practices, tools, and knowledge that enable and accelerate the envisioned transformation of the greater United States aerospace enterprise through people and processes"[1]. Since 1993, the LAI consortium has executed its mission with a closed loop knowledge cycle that encompasses: establishing goals and priorities; academically rigorous research; development of products such as enterprise improvement tools, publications and curriculum; dissemination of the findings and tools through workshops and conferences; implementation and testing of these findings and products in member organizations; and reflective adjustment to the program agenda. Over 100 graduates student theses have been completed, and a family of tools have been developed for enterprise transformation. Many industry and government presentations have been given on implementation experiences and outcomes. These provide a rich resource of data and illustrations. Most all of the LAI publications and presentations are publicly available on the LAI website, along with extensive information about LAI, its members, and its meetings and workshops.

Educational Network (EdNet)

EdNet[2] is headquartered at MIT in Cambridge, MA, is made up of 32 university partners in the US and UK, and is supported by this paper's authors (Figure 1). Each school has signed a No Cost Collaborative Agreement with MIT that covers sharing of intellectual property, governance, and resources. Any college or university whose graduates are employed by the LAI members is eligible to join.

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[1] http://lean.mit.edu/
[2] http://lean.mit.edu/ednet

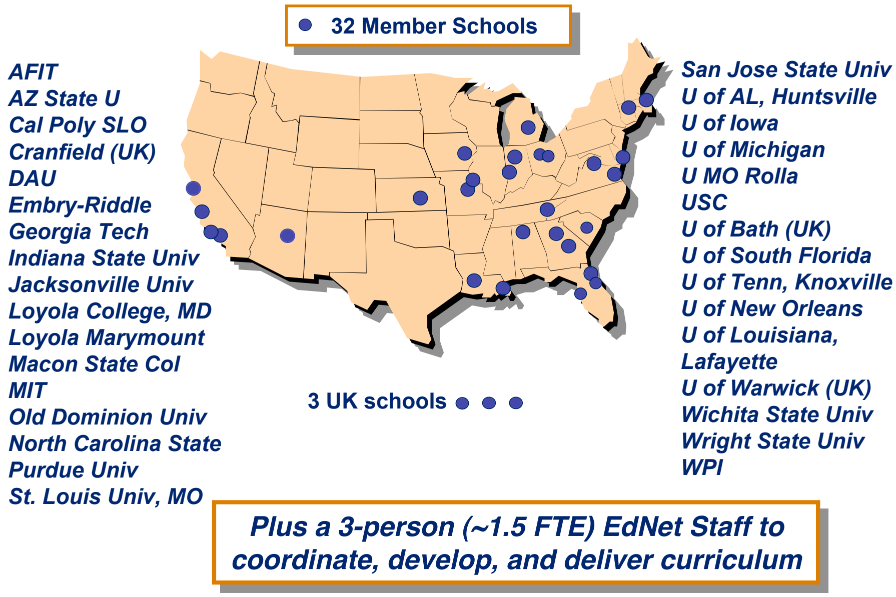

Figure 1 – Education Network Members – April 2007

The EdNet vision and mission are:

Vision: EdNet is a learning community dedicated to creating, deploying, and continuously improving curriculum for enterprise excellence; noticeably impacting workforce capability; and recognized as a model of collaborative innovation.

Mission: EdNet will leverage member's expertise and resources through collaboration and networking to accelerate the development and deployment of curriculum for achieving enterprise excellence.

EdNet activities can be lumped into three categories

- Networking: Annual members meeting; linking to LAI industry and government members; linking academics to academics
- Curriculum development, deployment and diffusion: LAI Lean Academy family of courses; bilateral curriculum sharing among members
- Organizational infrastructure: Website; e-mail lists; membership support

These activities support the development of faculty awareness, knowledge, and teaching of Lean Thinking principles, as reported in the remainder of this paper.

LAI Lean Academy® Course

The first and most extensive EdNet undertaking is the development and offering of the LAI Lean Academy® course[3], a one-week event that provides a hands-on introduction to lean and six sigma fundamentals. It is targeted for an audience with little or no background in lean thinking. The curriculum is sized to be adapted to a one-semester on-campus format, although flexibility is

[3] http://lean.mit.edu/leanacademy

needed to execute some of the active learning elements. Initially offered on-site at LAI industry members, the course has been successfully delivered to undergraduates and graduate students in engineering and management at several universities across the country. The modular architecture of the curriculum allows fragments to be integrated into existing subjects. This robust course links fundamental concepts with practical implementation through plant tours, lectures, simulations and active learning exercises. More advanced courses in Lean Engineering and Lean Supply Chain Management are under development, as are shorter versions of the basic LAI Lean Academy course.

Curriculum Overview

The curriculum is updated annually with version 5 currently being prepared. Each version has been reworked and expanded by the cadre of instructors who teach the courses using a CDIO type cycle, coordinated and led by the MIT EdNet team. This paper is based upon the 4th version, offered in 2006 to 12 audiences. The curriculum consists of 25 modules with about 400 slides with speaker notes offered over 5 days covering twelve Lean Enterprise Knowledge Areas:

1. Context for Lean Implementation in aerospace
2. Definition of Lean
3. Process concepts
4. Five fundamental principles of Lean Thinking
5. Lean tools and concepts
6. Lean office principles
7. Lean engineering principles
8. Lean supply chain management principles
9. Lean enterprise principles
10. Quality principles/Six Sigma
11. Role of people and organizations
12. Lean Implementation

A major emphasis has been placed upon active learning strategies [6] resulting in approximately 50% of the students time spent in about 40 encounters ranging from a day long Lego simulation of a manufacturing enterprise [7], to numerous team exercises, to short discussion sessions and "1 minute" quizzes.

Relationship to CDIO

The LAI Lean Academy course has considerable overlaps with the CDIO effort, including coverage of subject matter, borrowing of active learning and assessment techniques, and sharing of lessons learned. As to subject matter coverage, Appendix A provides a mapping of the LAI Lean Academy topics to the CDIO Syllabus Topics using a template developed by the MIT Department of Aeronautics and Astronautics. It can be seen that there is a high correlation in Syllabus topic group 4 *Conceiving, Designing, Implementing & Operating Systems in a Societal and Enterprise Context*. There are also high correlations with Syllabus topic groups 2.3 *System Thinking* and 3.1 *Teamwork*. There is some correlation with remaining Syllabus topic groups.

As explained in the next section, the LAI Lean Academy course has adopted the CDIO Syllabus MIT Activity Based Proficiency Scale to assess student and instructor proficiency. One of the side benefits of this is that the measures of student proficiency in LAI Lean Academy knowledge areas can be compared to the desired levels of proficiency determined by MIT and noted in parentheses next to each Syllabus topic in Appendix A. Broadly, the student proficiency after taking a LAI Lean Academy is about at the desired level.

VALUE Self-Assessment

The EdNet developed a self-assessment tool for students and instructors to measure their level of proficiency in the twelve Knowledge Areas given earlier. Proficiency levels are based on the CDIO Syllabus MIT Activity Based Proficiency Scale with an added Level 0 to accommodate the assumption that students would have no prior knowledge of Lean Thinking topics:

Level 0	UNAWARE	To have no exposure to or knowledge of
Level 1	AWARE	To have experienced or been exposed to
Level 2	READY	To be able to participate in and contribute to
Level 3	CAPABLE	To be able to understand and explain
Level 4	SKILLED	To be skilled in the practice or implementation of
Level 5	EXPERT	To be able to lead or innovate in

The tool named VALUE includes tips for self-assessment to help the user determine what level their experience and knowledge map to, and how to fill out the response. The one page score sheet extracted from the VALUE document is given in Appendix B. The self-assessment is administered before and after the course, and periodically given to instructors to track their proficiency. Like any other self-assessment, its fidelity is limited by the judgment of multiple responders.

Figure 2[4] shows the overall levels of proficiencies for 10 of the 12 2007 course offerings. It can be seen that, except for the far right bar, students start with a range of proficiencies hovering around Level 1 AWARE, and end the course close to Level 3 CAPABLE. This final level meets the course learning objectives and aligns with the content and learning exercises. It should be noted that each class can have a wide variation of before and after student proficiencies and the data in Figure 5 are each averaged over 20-40 students.

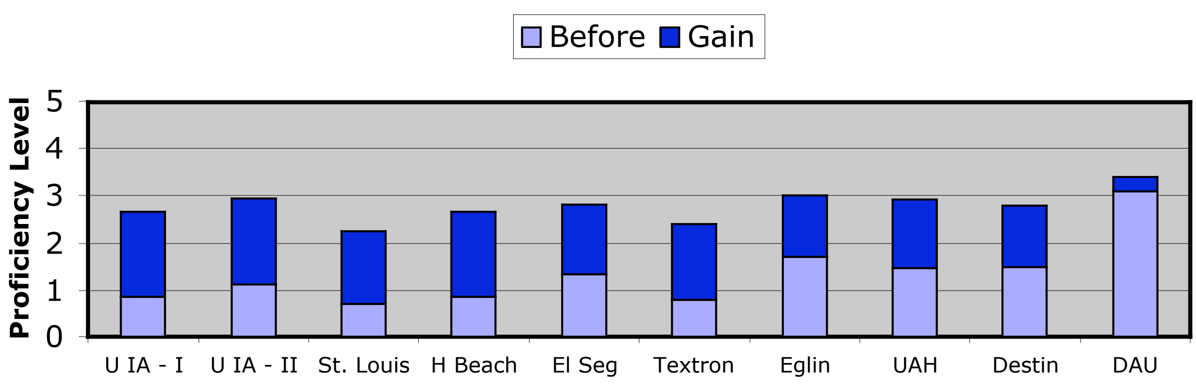

Figure 2 – Proficiency levels for 10 LAI Lean Academy® courses offered in 2007

[4] The interested reader might want to compare these proficiency levels those shown in parentheses in Appendix A.

The DAU course audience was comprised of 30 faculty and instructors who were being introduced to the course. On average, they already had Level 3 proficiency so the course did little to improve it. The curriculum was not designed to get students to Level 4.

Enhancing Faculty Competency

We now turn to the main question this paper addresses which is "Has the EdNet and its LAI Lean Academy course contributed to the development of faculty competency for teaching lean thinking, and if so how has it done so?" To answer this question with quantitative data, we conducted a survey of instructors who had taken and/or taught a LAI Lean Academy course. This is a large subset of faculty who have participated one way or another in EdNet.

Survey

The survey was comprised of four questions: 1) demographic information of the responder, 2) their change in VALUE proficiency during their involvement with EdNet, 3) how various EdNet activities had helped improved their competency, and 4) what the most valuable contribution EdNet had made to improving their competency. Surveys were sent to 53 U.S. instructors affiliated with 22 schools, with 20 replies received. However an unrepresentative sample of only 2 replies were received from 16 instructors in the two US government schools. This pool of instructors was removed to leave 18 responses from 11 schools from a total pool of 37 instructors representing 20 schools with the profiles shown in Table 1.

Table 1 – Survey Profile for Private & State Universities

Population	Instructor Rank			Institution		Discipline		Academy Instructor
	Tenure	Instruct	Other	Private	State	Eng'g	Mgm't	
Survey (37)	48%	30%	22%	38%	62%	51%	49%	81%
Response (18)	39%	39%	22%	50%	50%	55%	44%	100%

Legend for Table 1 Columns

Tenure	Tenure or tenure track appointment
Instruct	Adjunct faculty, professor of the practice, part time regular instructor
Other	Occasional campus instructor, industry or retired industry
Private	Private U.S. university or college
State	State university
Eng'g	Mechanical, aerospace, industrial or systems engineering department
Mgm't	Business or management school department
Academy Instructor	Has been an instructor in one or more LAI Lean Academy courses

Growth in Faculty Competency

Figure 3 shows the average proficiency level currently and before the instructors became involved in the EdNet, and the corresponding standard deviations. On average, the instructors increased their proficiency by one full level, from being CAPALBE or "able to understand and explain" to being SKILLED or "skilled in the practice and implementation of" the twelve knowledge areas.

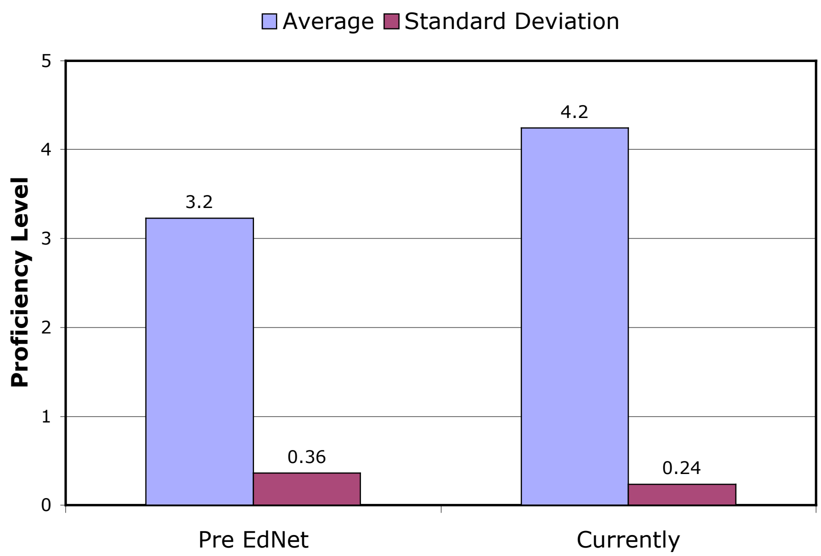

Figure 3 – Proficiency Levels for EdNet Instructors (N=18)

The distribution of average proficiency levels across the twelve knowledge areas is presented in Figure 4. Proficiency gains are pretty uniform across the areas with greater gains than average in 3 areas (Context for Lean implementation in aerospace, Lean engineering principles, Lean Enterprise Principles) and lesser gains than the average in 2 areas (Quality principles/Six Sigma, Role of People and Organizations). It is apparent than on average, the instructors developed comparable competency across all the areas.

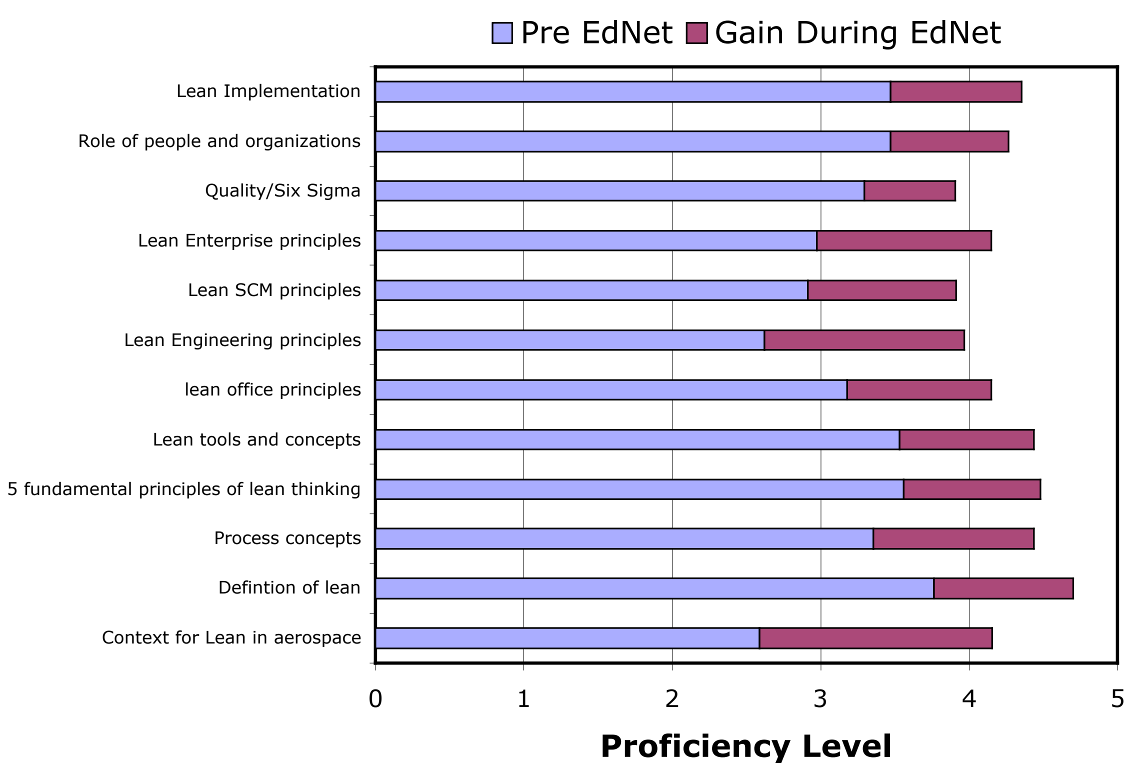

Figure 4 – Proficiency by lean enterprise knowledge area (N=18)

Figure 5 shows proficiency levels for each responding instructor, sorted with engineering faculty on the left and management faculty on the right (one management instructor did not provide data). It can be seen that a wide variation in instructor proficiency before becoming involved in EdNet was greatly reduced, giving a much narrower current spread. On average, pre EdNet and current proficiency levels for engineering and management faculty were about the same.

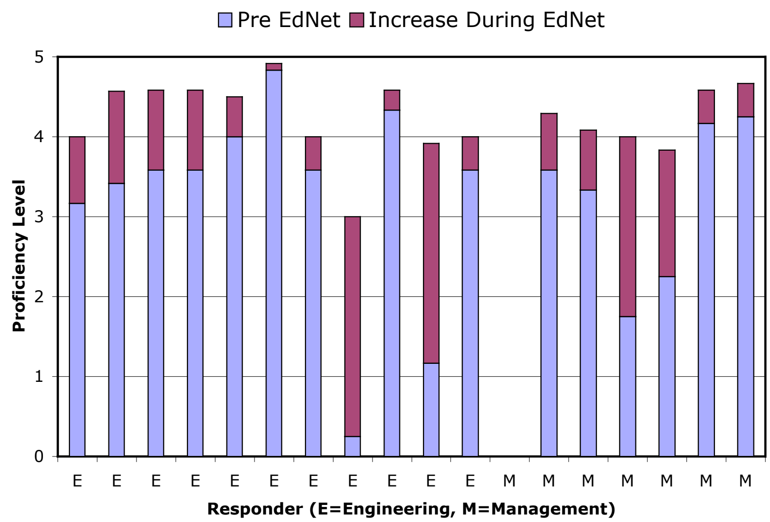

Figure 5 – Proficiency levels for each instructor

While Figures 3-5 show a strong correlation of improved proficiency during the instructor's involvement with EdNet, one cannot conclude a causal relationship from this data. During their association with EdNet the instructors were involved in other knowledge improvement activities such as research, teaching, reading and consulting. However it is interesting to consider several responses to the question "Please tell us what has been the most valuable contribution EdNet has made to improving your competency to teach lean principles and practices".

> *"I knew essentially nothing about Lean prior to becoming involved in EdNet. I now use Lean every semester within my aircraft design class." – Professor of Aerospace Engineering. Proficiency change from 0.3 to 3*

> *"The most valuable contribution EdNet has made to improve my competency to teach Lean has been through my involvement with the LAI Lean Academy. Attending the Lean Academy for instructors and supporting the teaching of a Lean Academy both have created a valuable resource pool for me [to] derive new ways to teach Lean principles and processes…." – Adjunct Instructor in Aviation. Proficiency change from 2.3 to 3.8*

> *"The opportunity to collaborate and interact with other EdNet members has been extremely valuable. The Lean Academy curriculum is modular and provides flexibility to be inserted as a module in existing courses. The real life examples illustrated in the Lean Academy curriculum are fabulous" – Professor of Engineering Management and Systems Engineering. Proficiency change from 3.6 to 4.0*

"Without a doubt, my involvement with LAI/EdNet has been the most important factor in not only improving my competency to teach lean principles and practices, but also in the development of my teaching in any context. In the context of lean, the EdNet curriculum, workshops, interactions with other educators through EdNet, and the tremendous partnership with our LAI member partner have greatly expanded my knowledge regarding the tools and applications of lean." – Assistant Professor of Management Sciences. Proficiency change from 1.8 to 4.

With these data and quotes, let's now turn to analyzing quantitative data on which EdNet activities contribute to improvement of instructor's competency.

EdNet Enablers

The survey asked instructors how EdNet activities have helped to improve their competency in *awareness, knowledge, and ability to teach* lean practices and principles. Specifically, the request was to *compare* EdNet activities with other means available to them for improving competency, such as research, consulting, teaching, reading, practicing, etc. The desire was to get a *relative comparison* on the value of EdNet for improving competency. A five-point scale was used, with the top two rankings being "Somewhat more than other ways" and "Much greater than other ways." Appendix C reports the specific questions asked and the data received. As an example, Figure 6 shows responses for one of the five questions: "Please compare EdNet activities to other ways of improving your ***teaching of the fundamentals*** of lean practices and principles."

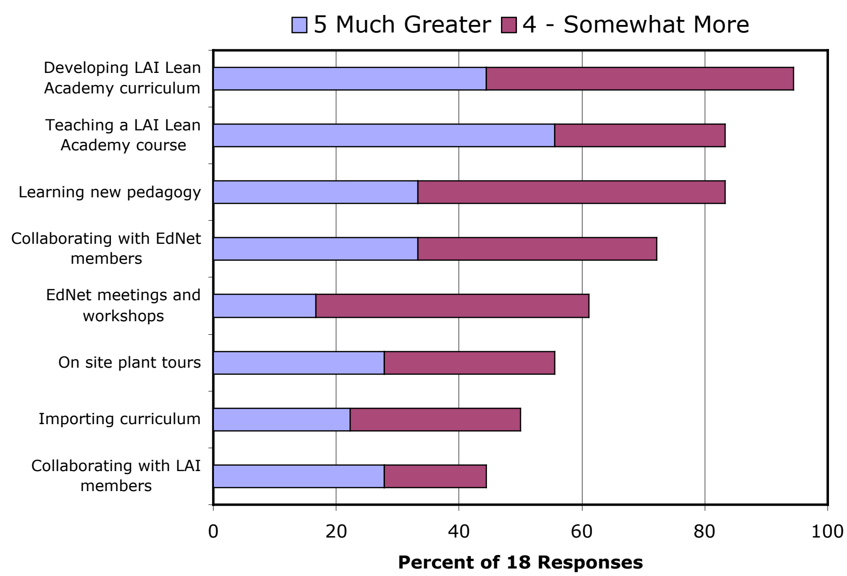

Figure 6 – EdNet activities contributing to competency in teaching of Lean Fundamentals

For this example, the highest ranking activity was *Developing Lean Academy Curriculum*. Two-thirds (67%) or more of the responders ranked four EdNet activities in the top two brackets compared to other ways available to them for improving their competency to teach the fundamentals of Lean Thinking. The remaining activities were also of value.

The data from Figure 6 and the other competency areas reported in the Appendix are summarized in Table2. Activities rated highest (in come cases there were ties) and which 67% or more of the responders rated in the top two survey ranks are shown.

Table 2 – Most valuable EdNet activities for improving competency

	Competency Areas				
EdNet Activities	**Awareness of Implementation**	**Knowledge of Fundamentals**	**Knowledge of Application**	**Teaching of Fundamentals**	**Teaching of Application**
Developing LAI Lean Academy curriculum	(green)	(green) ☆	(green) ☆	(green) ☆	(green)
Teaching an LAI Lean Academy course	(green) ☆	(green)	(green)	(green)	(green) ☆
Collaborating/partnering with EdNet members	(green) ☆	(green) ☆	(green)	(green)	(green)
On site plant tours	(green)	(green)	(green) ☆		(green)
Learning new pedagogy from EdNet members				(green)	(green)
Collaborating/partnering with LAI members	(green)				
EdNet meetings and workshops	(green) ☆				
Importing LAI Lean Academy or other curriculum					
Taking an LAI Lean Academy course					

Legend	(green)	**67% or more rated this (4) “somewhat more”or (5) “much greater”**
	(green) ☆	**Top EdNet activities for this competency area**

This data clearly shows that collaboratively developing curriculum and teaching the LAI Lean Academy courses are the most valuable EdNet activities for improving competency in the five areas.

> *“Developing the curriculum with a group of diverse stakeholders has brought a richness to the material that I could not develop alone. It has required me to rethink assumptions, review examples, stretch my thinking, and incorporate new ways of teaching and learning.” – Industry Systems Engineer& occasional instructor. Proficiency change 4 to 4.5*

On site plant tours are also provide value, a finding supported multiple times in responses to the written question such as:

> *“The plant tours have been the MOST VALUABLE contribution EdNet has made to improving my competency in teaching lean principles and practices, and to understanding what is going on in the government and aerospace in the lean arena.” – Professor Emerita of Supply Chain Management. Proficiency change from 3.6 to 4.3*

When it comes to teaching competency, instructors have benefited from learning new pedagogy.

> *“Learned the importance and application of ‘active learning’ to the effectiveness of presentations and the degree to which active learning exercises improve student*

retention."-Part time Senior Lecturer of Aeronautics and Astronautics. Proficiency change from 4.8 to 4.9.

In terms of developing competency, these activities rated significantly higher than attending meetings, taking a course or importing curriculum. Recalling that the question asked for a comparative value assessment, the implication is that these activities were more valuable than traditional means available to faculty for improving competency. What can be learned from this?

Discussion

The survey data yields two significant findings:

1. Participation in EdNet by group of engineering and management instructors is correlated with a change in their proficiency in Lean Enterprise knowledge by one full point on the CDIO Syllabus MIT Activity Based Proficiency Scale, or from being "Capable" to being "Skilled"
2. That the CDIO approach itself – conceiving, designing, implementing and delivering curriculum – has been the most important contribution EdNet has made to improving instructor competency.

The findings are qualified by being from a sample of 18 instructors, representing a pool of 37 as shown in Table 1. However these instructors come from 11 schools and represent both engineering and management disciplines.

An annual CDIO cycle has been used for the curriculum development, starting with a two-day workshop in late summer to review the data and experiences from LAI Lean Academy offerings during the year[5]. Typical attendance at this workshop has been around 15 instructors. Plans, roles and responsibilities are established for curriculum revision. Revisions are made during the fall by the distributed team with coordination and integration led by the EdNet staff. The new version of the curriculum has been field tested in January with an offering to a new group of instructors (the DAU offering of Figure 2), thereby widening the cohort of EdNet instructors. Improvements from the field testing are incorporated in late winter and the new curriculum is available for use by spring.

The EdNet instructors are used to teach LAI Lean Academy offerings for the LAI members, as part of open-enrollment offerings by University of Alabama Huntsville, and on the campus of EdNet colleagues. The course has been integrated into the USC Industrial and Systems Engineering curriculum and the Univ. of Iowa evening MBA program. Fragments of the curriculum have been integrated into the curriculum of most of the EdNet instructors.

The finding that active collaboration is the most valuable way to improve understanding and knowledge is in line with findings emerging from the study of product development in large organizations. Carlile [e.g. 8] has developed a theory of knowledge transfer across organizational units based on the concept of "boundary objects". The boundary object is a device such as a CAD drawing or prototype that enables communication among stakeholders

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[5] Microsoft has graciously hosted this event on their Redmond, WA campus and provided an exceptional venue for collaborative engagement.

who have different backgrounds, perspectives, or lingo, such as between engineering and manufacturing. Bernstein [9] investigated how engineers from different disciplines effectively work together to solve a particular design problem. He found that collaborative participation in a joint activity such as test was much more effective in developing a shared understanding than just common observation of a boundary object. Specifically, Bernstein observed:

> "These results also shed additional light on the concept of "boundary objects" (e.g., an artifact such as a drawing, part, etc., that is shared between individuals from different groups or specialties). In some sense, the results from a test can be viewed as a boundary object. However, it is not the sharing of the results alone that was important. What was also important was the consensus that was initially required to *create* the object. When that agreement was lacking, the utility of the object was reduced."

The take-away from this study is that this CDIO approach works for improving faculty competency and curriculum development because it is a "boundary experience" – a shared undertaking by which the participants gain knowledge and understanding from new and different fields.

Summary

Results from this study reveal that 18 instructors have significantly improved their competency to teach Lean Thinking during their affiliation with the LAI EdNet. The 18 instructors are representative of a larger survey pool of engineering and management tenure/tenure track and non-tenure faculty from public and state universities. On average, the instructor's proficiency in twelve Lean Enterprise knowledge areas has increased a full level on the CDIO Syllabus MIT Activity Based Proficiency Scale, from 3.2 to 4.2, or from being "capable" to being "skilled"

The EdNet activities which have most contributed to their improve competency form a CDIO-like cycle of collaborative defining, developing and implementing and using curriculum for the LAI Lean Academy® course. This is supported by EdNet activities such as plant tours, workshops and partnering with Lean Aerospace Initiative industry and government members to improve their awareness of lean practices and principles. Learning new pedagogy from EdNet staff and colleagues has also been an important contribution to growing teaching competency. Participation in these EdNet activities has contributed "somewhat more" or "much greater" than other ways available to the faculty (research, consulting, teaching, reading, etc.) to improving their competency.

Acknowledgements

Many people have contributed to the formation and evolution of the EdNet and the LAI Lean Academy® course. The authors would like to especially acknowledge Dr. Alexis K. Stanke who was instrumental in the formation of both the EdNet and the LAI Lean Academy course. The EdNet would not have been possible with out the sustained commitments of Richard Lewis, Retired COO of Rolls Royce Indianapolis, J-P Besong, Senior VP of e-Business and Lean Electronics at Rockwell Collins, and George Reynolds, Director of Industry & University Initiatives Engineering of Northrop-Grumman Electronics, and the LAI Executive Board.

References

[1] Womack, J, Jones, D., Roos, D., *The Machine that Changed the World*, Rawson Associates, 1990
[2] Womack, J., Jones, D., *Lean Thinking*, Simon & Schuster, 1996
[3] Harry, M., & Schroeder, R., *Six Sigma*, Doubleday, 2000
[4] Goldratt, E., *Theory of Constraints*, North River Press, 1999
[5] Murman, E., et al, *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*, Palgrave, 2002
[6] Candido, J, Murman, E, McManus, H., "Active Learning Strategies for Teaching Lean Thinking", Proceedings of the 3rd International CDIO Conference, Cambridge, MA, June 2007
[7] McManus, H., Candido, J., Murman, E., "Teaching Lean Thinking Principles Through Hands-On Simulations", Proceedings of the 3rd International CDIO Conference, Cambridge, MA, June 2007
[8] Carlile, P., "Transferring, Translating and Transforming: An Integrative Framework for Managing Knowledge across Boundaries" Organization Science 15 (5) (2004): 555-568
[9] Bernstein, J., "Multidisciplinary Design Problem Solving on Product Development Teams", MIT PhD Thesis in Technology, Management and Policy, Sept 2000

Biographical Information

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Appendix A - Mapping of LAI Lean Academy® Course to CDIO Syllabus Topics

Taught (T): Implies topic is Introduced
- Explicitly linked to a module learning objective
- Addressed with an active learning exercise
- Likely reinforced in other modules

Introduced (I)
- Explicitly covered on at least one slide

Blank:
- Topic not addressed in LAI Lean Academy coure

2 Personal and Professional Skills and Attributes		
2.1 Engineering Reasoning and Problem Solving	**T**	**I**
2.1.1 (4.4) Problem Identification and Formulation		
2.1.2 (4.3) Modeling		
2.1.3 (4.0) Estimation and Qualitative Analysis		●
2.1.4 (3.7) Analysis with Uncertainty		●
2.1.5 (3.8) Solution and Recommendation		
2.2 Experimentation and Knowledge Discovery	**T**	**I**
2.2.1 (3.4) Hypothesis Formulation		
2.2.2 (3.0) Survey of Print and Electronic Lit.		
2.2.3 (3.6) Experimental Inquiry		
2.2.4 (3.3) Hypothesis Test, and Defense		
2.3 System Thinking	**T**	**I**
2.3.1 (2.9) Thinking Holistically	●	
2.3.2 (2.6) Emergence and Interactions in Systems		●
2.3.3 (2.7) Prioritization and Focus		●
2.3.4 (2.9) Trade-offs, Judgment and Balance in Resolution		●
2.4 Personal Skills and Attitudes	**T**	**I**
2.4.1 (3.4) Initiative and willingness to take risks		
2.4.2 (3.4) Perseverance and flexibility		
2.4.3 (3.6) Creative Thinking		
2.4.4 (3.8) Critical Thinking		
2.4.5 (3.4) Awareness of one's personal knowledge, skills and attitudes	●	
2.4.6 (3.1) Curiosity and lifelong learning		
2.4.7 (3.4) Time and resource management		
2.5 Professional Skills and Attitudes	**T**	**I**
2.5.1 (3.7) Professional ethics, integrity, responsibility & accountability		
2.5.2 (2.7) Professional behavior		
2.5.3 (2.7) Proactively planning for one's career		●
2.5.4 (2.9) Staying current on World of Engineer		

3 Interpersonal Skills: Teamwork and Communication		
3.1 Teamwork	**T**	**I**
3.1.1 (3.4) Forming Effective Teams	●	
3.1.2 (4.0) Team Operation	●	
3.1.3 (2.7) Team Growth and Evolution	●	
3.1.4 (3.4) Leadership	●	
3.1.5 (3.0) Technical Teaming		
3.2 Communication	**T**	**I**
3.2.1 (3.5) Communication Strategy		
3.2.2 (3.8) Communication Structure		
3.2.3 (3.9) Written Communication		
3.2.4 (3.1) Electronic/Multimedia Communication		
3.2.5 (3.4) Graphical Communication		
3.2.6 (4.1) Oral Pres. and Interpersonal Com.		●

4 Conceiving, Designing, Implementing & Operating Systems in the Societal and Enterprise Context		
4.1 External And Societal Context	**T**	**I**
4.1.1 (2.2) Roles and Responsibility of Engineers		
4.1.2 (2.5) The Impact of Engineering on Society		
4.1.3 (1.7) Society's Regulation of Engineering		
4.1.4 (1.4) The Historical and Cultural Context		
4.1.5 (2.2) Contemporary Issues and Values		●
4.1.6 (2.1) Developing a Global Perspective		●
4.2 Enterprise And Business Context	**T**	**I**
4.2.1 (1.6) Appreciating Different Enterprise Cultures		●
4.2.2 (2.2) Enterprise Strategy, Goals and Planning	●	
4.2.3 (1.8) Technical Entrepreneurship		
4.2.4 (1.8) Working Successfully in Organizations		●
4.3 Conceiving and Engineering Systems	**T**	**I**
4.3.1 (3.2) Setting System Goals and Requirements	●	
4.3.2 (3.2) Defining Function, Concept and Architecture		●
4.3.3 (3.1) Modeling of System and Ensuring Goals Can Be Met		●
4.3.4 (3.0) Development Project Management	●	
4.4 Designing	**T**	**I**
4.4.1 (3.9) The Design Process		●
4.4.2 (2.9) The Design Process Phasing and Approaches		●
4.4.3 (3.4) Utilization of Knowledge in Design	●	
4.4.4 (3.4) Disciplinary Design		
4.4.5 (3.4) Multidisciplinary Design		●
4.4.6 (3.5) Multi-objective Design	●	
4.5 Implementing	**T**	**I**
4.5.1 (2.3) Designing the Implementation Process	●	
4.5.2 (2.1) Hardware Manufacturing Process	●	
4.5.3 (2.4) Software Implementing Process		●
4.5.4 (2.4) Hardware Software Integration		●
4.5.5 (2.7) Test, Verification, Validation & Cert.	●	
4.5.6 (2.0) Implementation Management	●	
4.6 Operating	**T**	**I**
4.6.1 (2.6) Designing and Optimizing Operations	●	
4.6.2 (2.2) Training and Operations		
4.6.3 (2.4) Supporting the System Lifecycle	●	
4.6.4 (2.4) System Improvement and Evolution		●
4.6.5 (1.5) Disposal and Life-End Issues		
4.6.6 (2.3) Operations Management	●	

Appendix B – LAI Lean Academy® Course VALUE Score Sheet

LEVEL 0:

To have no exposure to or knowledge of

- Have I never heard about these topics at all?
- Have I only heard about these topics in casual conversation?

LEVEL 1:

To have experienced or been exposed to

- Have I had some organized introduction or instruction to these topics?
- Have I used some of these topics in my work?
- Can I tell myself what these topics really mean?

LEVEL 2:

To be able to participate in and contribute to

- Do I know enough about these topics that I can comprehend what other people mean?
- Can I participate in give-and-take dialog on these topics?
- Have I ever participated in an event when this topic was used?
- Did I contribute to the discussion or action surrounding this topic?

LEVEL 3:

To be able to understand and explain

- To whom could I explain these topics?
- What would I actually tell them?
- Have I ever actually explained any of these topics to someone else?
- Have I written something about these topics?
- Have I given a presentation where I explained these topics or needed these topics to explain about a lean activity?

LEVEL 4:

To be skilled in the practice or implementation of

- Have I applied my knowledge in this area? How did I apply it?
- Was I able to improve enterprise value creation by applying my knowledge in this area?
- Have I applied my knowledge more than once?
- Did I learn new things about this area by applying my knowledge?

LEVEL 5:

To be able to lead or innovate in

- Have I ever lead a lean activity in this area?
- Have I taught someone else about these topics?
- Have I discovered new knowledge that has improved lean practices in this area?

LEVEL	KNOWLEDGE AREA
☐	**Context for Lean implementation in aerospace:** External factors driving change; transformation challenges; relationship to other industries; demonstrated benefits
☐	**Definition of Lean**: Definition of lean; 7 wastes; internal/external customers; value
☐	**Process concepts**: process elements; process maps; lead & cycle time; capacity; throughput; balancing; process capability
☐	**Five fundamental principles of Lean Thinking:** value, 3 types of waste, value stream mapping, flow, pull, perfection
☐	**Lean tools and concepts:** VSM; 5S; 5 whys; takt time; setup reduction; single piece flow; andon; kanban; standard work; JIT
☐	**Lean office principles**: value of removing time from administrative processes; identfy and appy lean thinking and analysis tools to office processes
☐	**Lean engineering principles**: customer value; product lifecycle; lean engineering tools; IPTs, info wastes PDVSM, DFSS
☐	**Lean supply chain management principles**: supplier added value; make-buy; supplier certification; tiers; vendor-managed inventory; 3PL; IT integration; suppliers as partners
☐	**Lean enterprise principles:** stakeholders; core, extended and lean enterprises; lifecycle and enabling infrastructure processes; lean enterprise management
☐	**Quality principles:/Six Sigma** product & process quality; 7 basic quality tools; DFSS; SPC; impact of quality on flow, Cp & Cpk
☐	**Role of people and organizations**: employee satisfaction; organizational structure; culture; leadership & management; 3 elements of collaboration; matrix organization; IPT
☐	**Lean Implementation**: Kaizen; continuous improvement; DMAIC

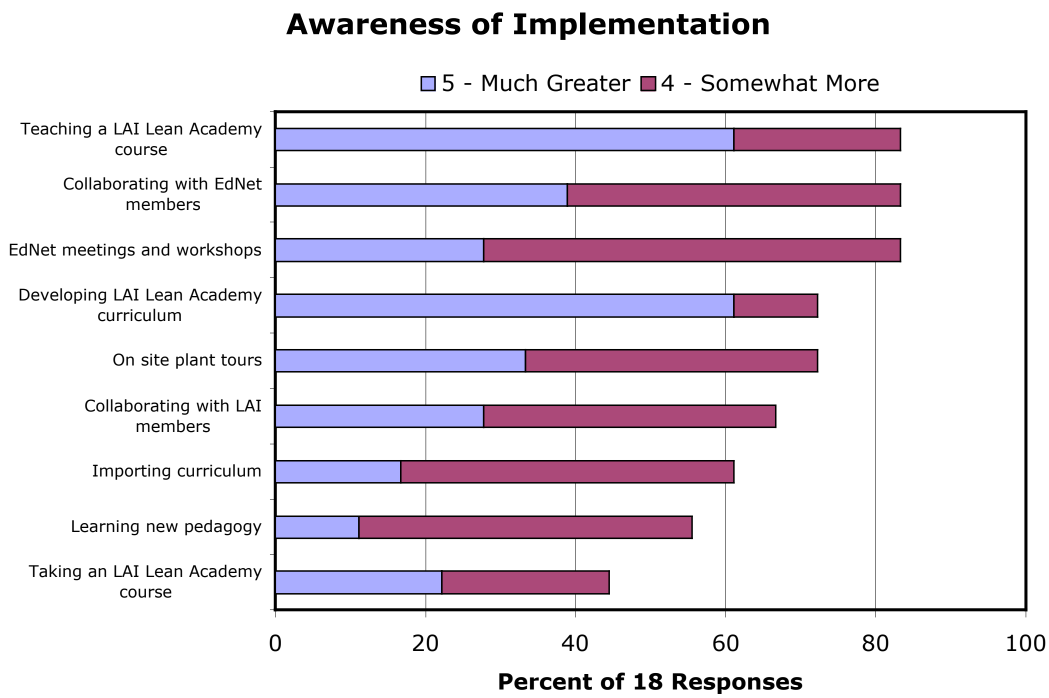
Appendix C – Survey Data

Please rate how EdNet activities have contributed to improving your competency compared to other ways available for improving your competency (research, consulting, teaching, reading, practicing, etc.), using the following scale:

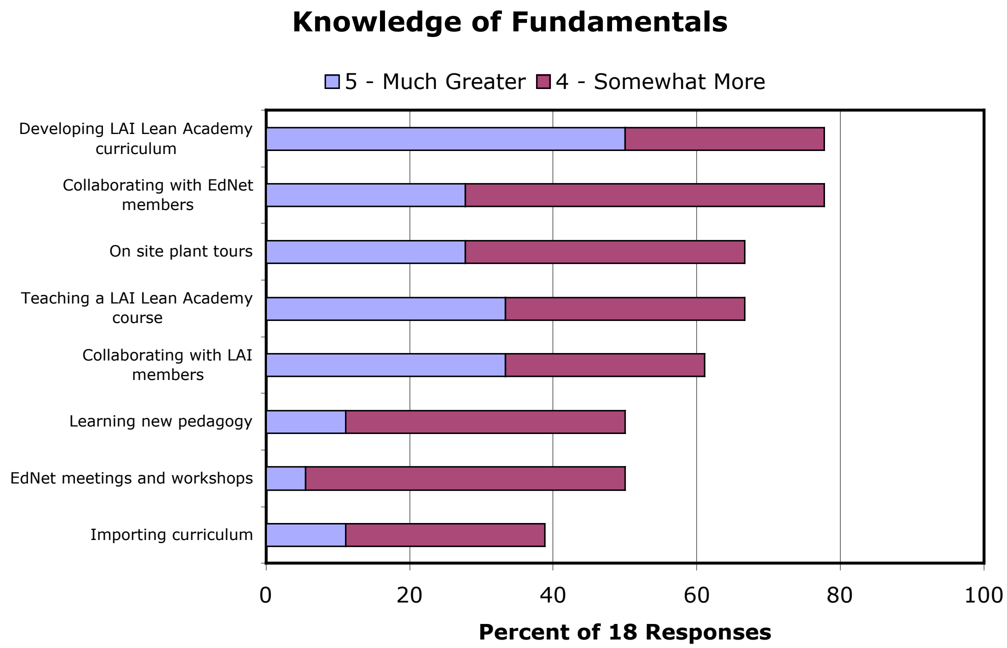
1. Very little compared to other ways
2. Somewhat less than other ways
3. About the same as other ways
4. Somewhat more than other ways
5. Much greater than other ways

N/A Does not apply to me.

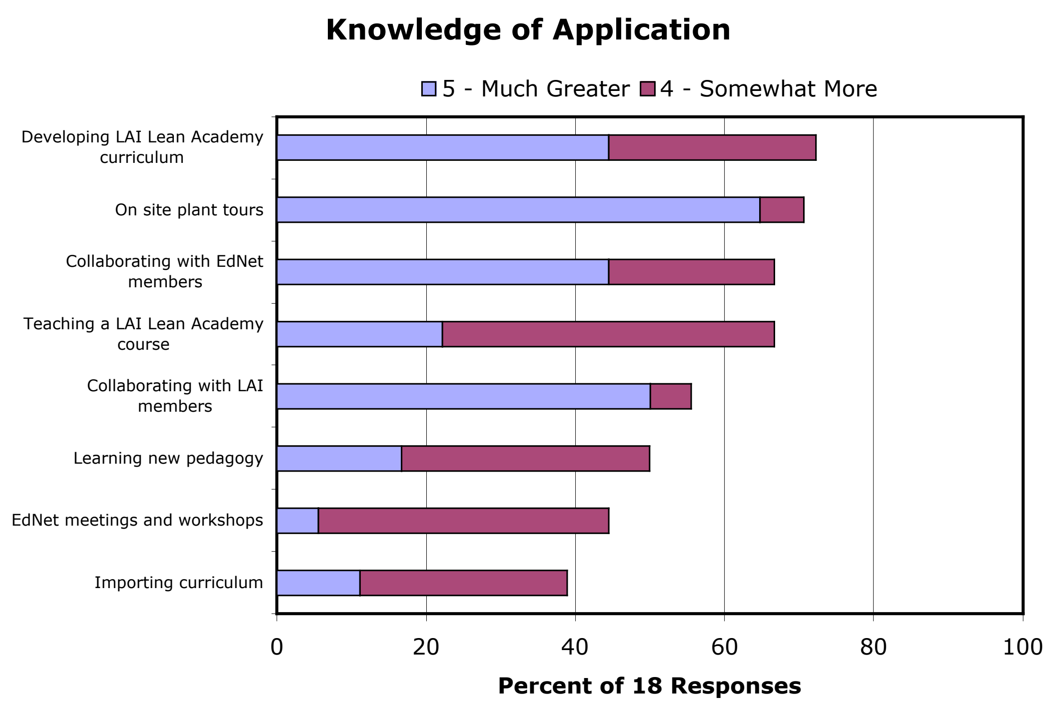
I – Please compare EdNet activities to other ways of improving your ***awareness*** **of industry and government implementation** of lean practices and principles.



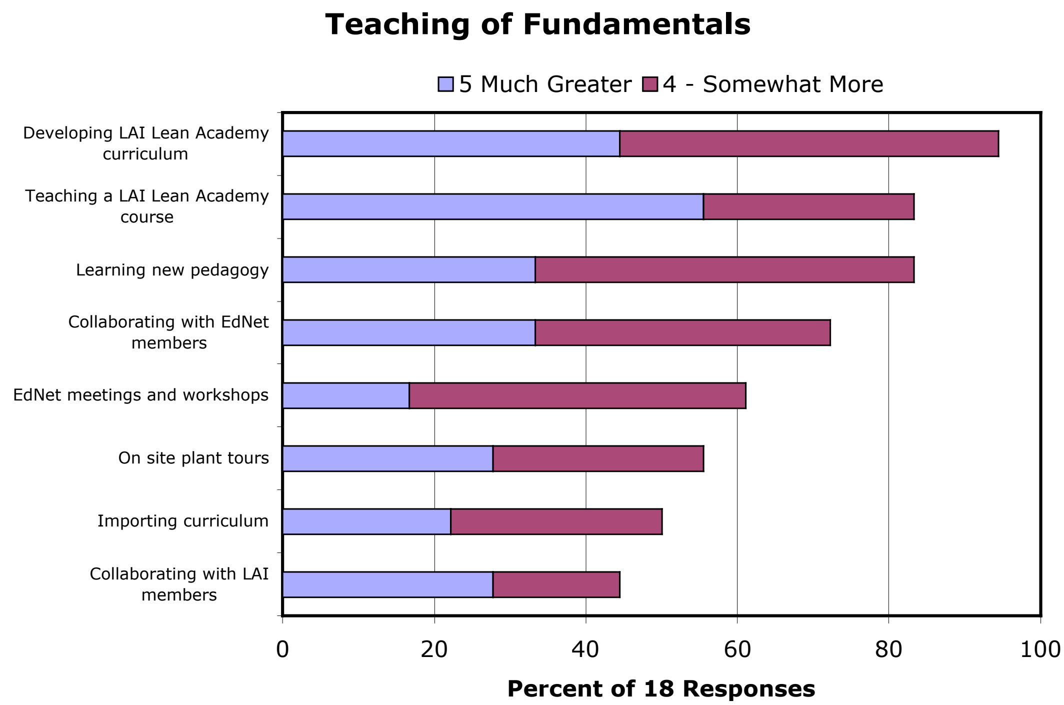
II – Please compare EdNet activities to other ways of improving your ***knowledge of the fundamentals*** of lean practices and principles.



III – Please compare EdNet activities to other ways of improving your ***knowledge of the application*** of lean practices and principles.



IV – Please compare EdNet activities to other ways of improving your ***teaching of the fundamentals*** of lean practices and principles.



V – Please compare EdNet activities to other ways of improving your ***teaching of the application*** of lean practices and principles.