Scaling MEMS Education Offerings: SCME’s Synergy Story

INTRODUCTION

As the demand for Micro-technology technicians continues to increase, there is a critical need for a standardized/readily available Microsystems curriculum to facilitate rapid dissemination of these highly skilled individuals. In an effort to lay the foundation for Microsystems education, the National Science Foundation (NSF) funded the creation of the Southwest Center for Microsystems Education (SCME) under its Advanced Technological Education program in 2004 and 2009 (DUE Grant Nos. 0402651, 0902411). The SCME has recently moved and is located at the University of New Mexico Manufacturing Training and Technology Center (MTTC) in Albuquerque, New Mexico, United States.

The following paper describes SCME’s “story” as to how they have actively engaged industry to improve their instructional materials design and delivery which will reduce the time to market, and increase penetration. Since the SCME has developed dozens of Learning Modules and several hands-on kits, it has become apparent that there is a need to improve the promulgation of these materials to educational organizations on a national scale in order to impact a larger segment of the student population. Utilizing lessons from the “Research, Practice and Transformation through Synergy Project” (DUE No 0903224) and “lean” manufacturing methodologies, the SCME is beginning to experience broader impact from their educational offerings that are now being duplicated by other projects/centers (scale). Specifically, utilizing the concepts of Training Within Industry’s Job Instruction, students and secondary/post-secondary alike not only receive an educational overview from workshops, but utilize the training they receive to demonstrably bring these skills back to the classroom and ultimately to industry. The faculty participants in these activities have a better understanding of the materials and a template to follow for when they facilitate their students’ learning and acquisition of micro technology knowledge and skills. Industrial participants immediately bring enhanced knowledge and skills back to their organizations. Additionally, SCME directly benefits from these “leaning” efforts thus becoming more efficient and further able to broaden their impact.

THE SYNERGY PERSPECTIVE

According to the Synergy 2010 Group’s Home Page (n.d.), the goals of the Synergy Collaboratory (a collaborative laboratory) for Research, Practice and Transformation are:

- Create and implement a program of professional growth and team development using Synergy methodologies to develop the skills and competencies necessary to achieve scale within a broader range of projects and initiatives in ATE community;
- Design and maintain a knowledge management system and process to support the capturing and dissemination of the knowledge and expertise resulting from our individual and collective efforts in achieving scale;
- Develop and leverage an ongoing academy of thought leaders focused on identifying and bringing together the best research and insights on overarching problems and needs in achieving scale and greater impact in the work of the greater ATE community; and
• Provide a toolkit of assessment tools and processes appropriate for the various stages of moving from aspiration to understanding to practice and to coaching.

A Synergy Innovation Coach works with a project or center’s Principle Investigator to lend the Synergy perspective. The Synergy Group gave guidance on what they envisioned the roles, activities and principles of the Innovation Coach to be, but did not dictate what the role would actually be; they let the centers define their role as it applied to their needs. SCME has defined their Innovation Coach role as follows: “The Innovation Coach is not the owner/driver of the project, but a reflector providing coaching that enables everyone to be thinking/behaving differently such that our projects scale. We need to look at things differently; thus we experiment with Synergy based tools and principles and share best known methods within the ATE community of practice.” There are four primary tools, or lens’ the Synergy process requires the Innovation Coach to view their project through. Among them are the Kellogg Logic Model, the Challenge Cycle, Dede Model, and the Dearing Attributes. The following four paragraphs reflect how SCME has interpreted the research/applications of these tools for their project under consideration (and may differ from the developers’ intended applications). For best descriptions, readers should go to the references cited!

SCME uses a logic Model developed from literature in the W.K. Kellogg Foundation’s Logic Model Development Guide (2001) and adopted by the Synergy Group to be a template for Advanced Technological Education Projects and Centers. The primary considerations for this model are: Inputs (resources that support the project); Activities (the main things the project does/provides); Outputs (the tangible results that are hoped to be achieved); Short Term Outcomes (the direct results of the activities/outputs such as knowledge, skills and attitudes; Mid-Term Outcomes (such as changes in behavior, policies and practice); and Long-Term Outcomes (changes according to broader impact intentions proposed in the grant proposal).

The Challenge Cycle is remarkably close to models used in action research within educational settings and/or the Plan, Do, Check, Act model used within industry. The key component of action research, and thus the Challenge Cycle, is action. According to Creswell (2005), citing Mills (2000), the creation of an action research plan includes identifying an area of focus, collecting data, analyzing/interpreting the data, and developing an action plan based on the results. This is done in a fashion according to Stringer’s (1999) Action Research Interacting Spiral consisting of multiple iterations of “look, think, act” in conjunction with Stringer’s (1999) Action Research Model of “Building the Picture (“look’”), “Interpret and Analyze (“think”)” and “Resolve Problem (“act”).” The basic idea of the Challenge Cycle is to understand the case/problem under consideration (using a logic model), analyze the problem via additional tools being developed by the Synergy Group, directly observe the current state of the problem in order to obtain field insights, develop resources (interventions) that address the problem, test the intervention on a small scale, and ultimately implement solution proposals and action plans to the most appropriate scale. As the action plans are executed, there is a new current state to consider. In the spirit of continuous improvement, this provides the Innovation Coach and project team to begin the cycle again.

The Dede/Microsoft Model (n.d.) was developed by Chris Dede (under a grant from Microsoft). Dede is a Harvard professor, researcher and Microsoft consultant who serves as a senior consultant/thought leader within the Synergy Group. The model identifies five
dimensions of scale that reflect an Innovation Coach’s considerations to make an intervention that is effective in one environment and making it useful across an appropriate spectrum of environments. These five dimensions are depth, sustainability, spread, shift and evolution. In depth descriptions of each, as well as sources of leverage and traps to avoid are described in much greater detail in Microsoft Education Scaling Demo web site.

The Dearing Attributes were developed by James Dearing, a Senior Scientist and Co-Director of the Center for Health Dissemination and Implementation Research in the Institute for Health Research, Kaiser Permanente Colorado, who also serves as a senior consultant/thought leader within the Synergy Group. Dearing (2007) says, “Innovation attributes are most often measured as the perceptions by potential adopters of the characteristics associated with a particular innovation. An innovation is broadly construed as anything perceived to be new by a potential adopter, inclusive of information, ideas, practices or techniques, programs or interventions, technologies, processes, and policies.” He identifies the following as the attributes innovation coaches should consider when scaling an intervention:

- **Effectiveness** – Will the innovation/intervention provide a better outcome, good results, and be better than alternatives?
- **Cost** - Will the innovation/intervention be better, faster, and cheaper than current state or alternatives?
- **Compatibility** - Will the innovation/intervention be applicable with existing beliefs and practices, and fit the goals/mission of potential/anticipated adopters?
- **Simplicity** - Will the innovation/intervention be easily understood and easy to apply/use by adopters?
- **Adaptability** – Can the innovation/intervention be applied across a wide range of different situations?
- **Observability** - Can the innovation/intervention impact/result be directly observed? This consideration is particularly important to SCME’s project as it ties together Logic Model considerations and “lean” considerations (which will be described later).
- **Trialability** - Can the innovation/intervention be “tried” without committing fully?

It should be noted that the Synergy project provided SCME with a catalyst to provide a roadmap for scaling and delivering on broader impact goals. A very serendipitous advantage is the consistency of the language that is slowly developing among the Synergy Group in general and SCME in particular. For the remainder of this paper, as SCMEs innovation/intervention and methodology are described, note that many of the above terms are italicized.

**HOW THIS RELATES TO SCME**

SCME’s goal is to enhance the capability of emerging technology to produce technicians for research and the production of hi-tech products. They not only produce educational materials but disseminate (scale) this knowledge to secondary and post secondary educators. Industry contributes their needs via Industry Advisory Boards and a National Visiting Committee. In order to spread/shift these educational materials to other institutions, SCME decided to create an innovation/intervention that would formalize a training methodology to achieve three outputs. These are: train the educators so they can better utilize the materials (referred to as Sharable Content Objectives or SCO’s based off of SCORM standards), support educators in their efforts...
to better educate their students; and to provide a vehicle for educators to scale, shift and evolve SCME’s materials via train-the-trainer sessions. This innovation/intervention can also be used to assist small start ups that research, develop and manufacture MEMs devices at the SCME’s home institution; the University of New Mexico’s Manufacturing Technology Training Center (MTTC) within the Mechanical Engineering program. SCME wants to bring value to these start ups as well as established MEMs manufacturers (which will be a topic of discussion as the Industry Advisory Board is reinvigorated, but is beyond the scope of this paper).

The problem SCME chose to address, prompted by needing a project to use the Synergy concepts experimentally to support the Synergy grant, was “SCME’s materials have a utilization rate of 15-20%. This needs to improve!” From a Synergy lens, SCME developed their logic model. Regarding Inputs: There are variable types of students (diverse blend of professional development, students, educators and industry oriented) that utilize the MTTC, workshops and kits. There is also a variable amount of money being spent to run workshops, develop, manufacture and distribute educational materials and kits. Cleanroom costs are fixed, but there is a variable cost for consumables. SCME is working off of previously evaluated success, grant goals, deliverables, and advice from the National Visiting Committee. Regarding activities: SCME offers numerous workshops, which include fabrication, safety, application topics as well as hands-on kits demonstrations which can be tied back to wafer processing knowledge and skills. SCME is creating Job Instructions for additional facilitators for workshops/kit demos and will provide these instructions with distribution of kits to encourage use/instill confidence in those teachers utilizing the kits. SCME will also improve our knowledge capture/suggestion system as misprocess events occur to improve process quality. Regarding Outputs: Where duplication (scaling) is desired, Job Instruction Breakdown Sheets for all kits/activities, and process specifications that are procedural in nature will be required. Regarding Outcomes: Additional skilled SCME facilitators, skilled technicians, skilled teachers and industry leaders will all be leveraged to add value to industry/education (including additional users of the MTTC for-profit and robust NVC contributors). Regarding Impact: Improved awareness/relationship with micro/nano industry, SCME sustainability, more educators utilizing SCME materials/resources, and methodologies that can be scaled for growth towards a national center. Ultimately, a higher number of skilled and knowledgeable workforce will be participating in the research, development and manufacturing of micro-technology based products.

The innovation/intervention SCME decided to use was the application of lean manufacturing methodologies with a shifted paradigm that focuses on “leaning educational experiences” to eliminate what SCME’s Innovation Coach considers “educational waste”. Through the application of the Training Within Industry (TWI) training methodology called “Job Instruction” (a precursor to lean manufacturing concepts), SCME has dramatically improved the dissemination of and utilization of their materials and educational offerings. SCME is also utilizing the Synergy models to create an intervention that will evaluate an illusive metric that is valuable to the NSF; the direct impact to students (which is in its early stage of development, and again is beyond the scope of this paper).

A paper on lean can not be complete without mentioning the Toyota Production System (TPS) or the seminal work by Bowen and Spears (1999). For all intents and purpose, Toyota created the TPS and thus the concept of Lean Production in Japan (oftentimes referred to as Lean
Manufacturing, Lean Thinking or simply “lean”) (Ohno, 1988; Womack, Jones & Roos, 1991; Monden, 1993; Rother & Shook, 1999; Fujimoto, 1999; Liker, 2004). What is less known is that the TWI methodology was according to Dinero (n.d.) and Wrona (2007), the “missing link” that connected the Japanese culture of Kaizen (continuous improvement) with their production prowess. There are numerous articles that “tell the story” of the emergence, disappearance, and reemergence of TWI within the United States. Dooly (2004), citing Dooly (1946) and McLean (2003), says, “Human resource development is a relatively young field in the U.S. that many believe it had its beginnings in the training-within-industry effort during World War II” (Dooly, 2004, p. 359). At the close of World War II, TWI as a “project” was terminated and in its place several efforts were established. One was named the American Society of Training Directors (1944) which later became the American Society for Training and Development (ASTD). Seminal in the TWI literature is Dooly’s (1946) The Training Within Industry Report 1940-1945 commissioned by the U.S. War Manpower Commission (1945), Bureau of Training, Training Within Industry Service. In Dooly’s report, he said, “We learned a great deal in wartime which we can and must carry over to peacetime in that field of industrial activity, which, for lack of a better name, is called ‘training’” (Dooly, 1946, p. 160). According to this report, of the 600 client companies monitored by the TWI Service throughout the war, 86% increased production by at least 25%, 100% reduced training time by 25% or more, 88% reduced labor-hours by over 25%, 55% reduced scrap by at least 25% and 100% reduced grievances by more than 25%. Unfortunately, American manufacturers saw TWI as a war program that was too costly to sustain. After the war, TWI was introduced to Japan along with the quality methods of Juran and Deming. Notably, Toyota embraced TWI as their primary method of training. Liker and Meier (2007), looking at the historical anecdotal evidence say, “It would appear that Toyota took the goals of TWI to heart, because it incorporated the concepts of the importance of people and their development into every aspect of their production system and throughout the company, including staff functions” (p. 36). Robinson and Schroeder (1993) provide an excellent document about how TWI was closed in the United States, and exported to Japan in the mid-1940’s by the Occupation authorities led by General MacArthur after World War II.

It was the aforementioned seminal work of Bowen and Spears that, quite literally, broke down the concept of lean into various rules and principles. How these appropriately enable lean thought is profoundly communicated by Jamie Flinchbaugh, co-founder and managing partner of the Lean Learning Center. Flinchbaugh (n.d.) says, “Principles, rules, theory and concepts are all examples of models. Models are by definition simplifications of reality. Because they are a simplification, there is no one model, no one theory, that is all encompassing and failsafe to use” (p. 7). For that reason, the Lean Learning Center, Bowen and Spears have articulated a set of principles, or more precisely, a model of how best to describe lean systems. The following principles and rules are collectively a model that were intended to guide SCME staff and their Innovation Coach as they learn, experiment and transform the organization.

SCME utilized these rules and principles in order to have common language in place to learn, internalize, and ultimately change the way SCME staff and educational offering participants “think” in order to embrace lean methodologies. This is important as lean transformations are based on standardized thinking within the organization. Flinchbaugh (n.d.) says, “Without shared mental models, the team responsible for lean transformation will have words with
different meanings, tools with different purposes and projects heading towards different visions…it is absolutely critical that their thinking is consistent with each other” (p. 7).

Much has been written on the topic of the four rules and five principles. For the purpose of this paper, in order to understand the context of what is critical for SCME and other potential adaptors who wish to **scale** using this methodology, is a common representation that describes the rules as a base (or foundation) of a house while the principles are represented by the walls and roof of the house. This is commonly referred to, within industry, as the house of lean. Flinchbaugh (n.d.) elaborates on these citing Bowen and Spears (1999) presenting the four rules as **structure every activity, clearly connect every customer/supplier, specify and simplify every flow, and improve through experimentation at the lowest level possible towards the ideal state.**

After one has built the foundation on the rules, the following principles apply (Flinchbaugh, n.d., p. 8-16). Principle one is **understanding current reality requires deep observation.** Those seeking to suggest improvements, according to this principle, must directly observe work/structure, and improve according to observable activities, connections between activities and the overall flows of the processes under observation. SCME brought an Innovation Coach/Industry Liaison on board to directly observe their offerings. Principle two is that *everyone systematically eliminates waste.* The seven primary wastes are identified and defined, all from the end customers’ or users perspective, as overproduction, transportation, motion, inventory, waiting, over-processing, and product/process defects. Occasionally, anecdotally speaking from an industry perspective, and continuing to emerge from an academic perspective, one will come across the term wasted human potential (people doing the work that they are not suited for and/or being underutilized) as an eighth waste (Suzaki, 1993; Womack & Jones, 2003; Macomber & Howell, 2004). While reporting on what the Innovation Coach observed, SCME’s Principle Investigator said, “Student Learning Time is our Production!” This led the Innovation Coach to observe waste as what he has coined “educational wastes”. These are:

- **Waiting** – There were several instances where participants could not see a demonstration and thus waited for instruction, limited equipment demanded waiting their turn, there were times the trainer/teacher was otherwise occupied, and several instances of waiting for the process to take place (referred to as “watching grass grow”).
- **Over Production** – There were several unnecessary examples of duplicate teaching, having to teach a skill “unplanned times” because of lack of a standardized method. One instructor contributed to environment of waiting on another who was “more expert” (due to lack of standards for teaching the UNM/SCME facilitators).
- **Over Processing** - Does the student need to know the skill under consideration? In several instances wafers need to be aligned on a tool prior to process. Although this action is required to process wafers, it is very hard to learn and is not necessarily a skill the student needs to take away (since a jig could be used to align the wafers).
- **Product/Process Defects** - Defects invariably induce waiting time! Student mistakes due to poor/non-standardized instruction create defects.
- **Motion** – Having effective work stations designed for the class/lab under consideration.
- **Inventory** – Having enough materials for a right sized class/lab.
- **Transportation** – Having materials central to class/lab such that students don’t need to waste time looking for necessary tools.
• Wasted Human Potential – SCME decided that for the time being, this was beyond the scope of addressing at the time.

Principle three is establish high agreement of both “what” and “how”. In other words, it is not enough to just agree on what needs to be improved, but also how improvement should occur. A general rule within this principle is that standardization is the foundation of continuous improvement; one must seek to create high agreement and no ambiguity. Flinchbaugh (n.d.) reemphasizes that sustainable change happens only at the systems level – again, lean is rules, not tools. Principle four is systematically complete problem solving activities. Every problem should be considered as an opportunity to focus on the ideal state, while decision-making remains at the point of activity (this is very important to keep in mind if utilizing Training Within Industry concepts). The fifth principle is create a learning organization. The term was popularized by Senge (1990) and, while none of his principles are compromised in lean thinking, emphasis is given to the ideas that leaders must be learners and teachers, and frequent points of reflection are employed.

The tool that SCME decided to experiment with was the TWI Job Instruction for all instances where standardization was necessary, and for the addressing of education waste. Job Instruction, utilizing a Job Breakdown Sheet, is a methodology that requires a set amount of teacher demonstrations/student iterations of the Important Steps (IS), Key Points (KP), and Reasons Why (RW). The original Job Instruction method, documented in Wrona and Graupp (2006), required three teacher demonstrations of IS, KP and RW followed by the student demonstrating their understanding by first performing the task without explaining anything, then three additional performances repeating the IS, KP and RW. IS are logical segments of the operation when something happens to advance the work or the learning experience. KP is anything in a step that makes/breaks the work, may injure a participant, makes the work easier (“knacks” and “tricks”) and any desired behavioral characteristics that the Job Instruction author wishes to instill in the participant at the time of the training. RW are the reasons why the IS/KP are done the way they are (according to adult learning theory, adult students perform better when they understand why they need to know what they need to know and why the key points make the work easier). Industry experiences have demonstrated that, with good specifications as the important steps, that IS/KP could be combined for the first iteration, and then KP/RW for a second iteration. Placing students in appropriate sized groups such that they can observe other students performing also reduces the performance demonstrations required by them. This is what SCME’s Innovation Coach calls “Job Instruction for Lean…or Leaning Job Instruction?” SCME Instructional Designers have adapted this methodology to create “Activity Guides” (the procedure by which the lab/kit is to be used) and “Activity Maps” the sequence for how/where the activities fit into the Sharable Content Objects/Module).

Job Instruction (Activity Guides and Activity Maps) will be/have been applied to improve SCME’s effectiveness in:

• Teaching educators how to use SCME products in the classroom. The educators can be later used to educate other teachers and their students.
• Incorporate Activity Guides and Activity Maps in the activities themselves both as an aid to the teachers and for the students to refer back to.
• Apply this principal in training skills for the fab (add value to MTTC and streamline the education of more common processes):
  – Wafer Handling
  – Art Wafer Process
    • Making a mask
    • Litho – coat, expose develop
    • Wet Etch – PPE
    • Resist Strip
    • Inspection
  – Activity Guides and Activity Maps
• Since this methodology is generally accepted by industry, this structured and standardized process will not only assist MTTC in being effective, but also can be applied and bring value to the industries served by SCME and their partners, as well as SCME/UNM instructors in the clean room (so there are not multiple ways skills are taught or one instructor more “expert” then another.

RESULTS

The results of these efforts to date have truly been astounding. One of SCME’s primary offerings is a four day Pressure Sensor manufacturing experience. Originally, all participants would stay together (usually 8-10) and spend three days in the manufacture of an “Art Wafer” (to demonstrate the process steps) and the actual “pressure sensor manufacturing process. After three days of “in fab” time, students were exposed to a full day of watching demonstrations of kits that demonstrated what participants learned at the micro level within a classroom at the macro-level. Participants would take home several kits, but external evaluations demonstrated a 15-20% utilization rate. In the new offering, by looking through the lean lens, and after much educational waste reduction, the workshop was redesigned to divide the participants into two groups; Group A and Group B. Each group is designed to handle 4-5 participants (still totaling 8-10), but now while Group A is learning a small segment of the Pressure Sensor Manufacture, Group B is watching and using Activity Maps and Activity Guides to actually build the kit with the instructor. The particular kit being demonstrated matches the experience the students receive in the MTTC fabrication facility (fab) portion so that they can understand the context of how the kit and the fab portion fit together. After the completion of this first activity, Group B goes to the fab and Group A performs the kit demonstration on the same segment. Notice that the Art Wafer segment was removed; this was deemed to be redundant with the Pressure Sensor Manufacture. The end result is that participants spend an accumulated two days of fab experience and two days of kit demonstrations, learn the kits by seeing/doing, take away the Activity Guides and Maps for reference, and they have more effective/efficient, crisp fab experiences to share the relevance of the experience in their classroom. SCME’s Innovation Coach is in the process of performing a “deep dive” evaluation of how participants of the three most recent Pressure Sensor Workshop participants have utilized their materials. As of this writing (February 25, 2011), 20 faculty have participated and 13 have been surveyed (the remaining seven only took the workshop in January of 2011 and will not be surveyed until March. Of the 13 active surveys, eight have returned feedback; seven of the eight have incorporated SCME’s materials into their classroom (for an 87.5% utilization rate).
SUMMARY

The above paper described how SCME has actively engaged industry to improve their instructional materials design and delivery which reduces the time to market, and increases penetration. Utilizing lessons from the “Research, Practice and Transformation through Synergy Project” (DUE No 0903224) and “lean” manufacturing methodologies, the SCME is beginning to experience broader impact from their educational offerings that are now being duplicated by other projects/centers (scale). Specifically, utilizing the concepts of Training Within Industry’s Job Instruction, secondary and post-secondary educators alike not only receive an educational overview from workshops, but now utilize the training they receive to demonstrably bring these skills back to the classroom and ultimately to industry. The faculty participants in these activities have a better understanding of the materials and a template to follow for when they train other teachers to utilize these materials, and facilitate their students’ learning and acquisition of micro/nano technology knowledge and skills. Additionally, SCME has directly benefited from these “leaning” efforts thus becoming more efficient and further able to broaden their impact.
REFERENCES


