Empowering Engineering Students to Learn How To Learn

Prof. Farrokh Mistree, University of Oklahoma

Farrokh Mistree holds the L.A. Comp chair and is the director of the School of Aerospace and Mechanical Engineering at the University of Oklahoma in Norman, Oklahoma. Mistree’s current research focus is on learning to manage uncertainty in multi-scale design (from molecular to reduced order models) to facilitate the integrated design of materials, product and design process chains. His current education focus is on creating and implementing, in partnership with industry, a curriculum for educating strategic engineers—those who have developed the competencies to create value through the realization of complex engineered systems.

Dr. Dirk Ifenthaler, University of Freiburg
Prof. Zahed Siddique, University of Oklahoma

Dr. Siddique is currently a professor at the School of Aerospace and Mechanical Engineering of University of Oklahoma. His research interests are in areas of product design, product platform design, and engineering education. He is the faculty advisor of the Sooner Racing Team (FSAE) and coordinator of the Mechanical Engineering Capstone Program.
Empowering Engineering Students To Learn How To Learn: A Competency-based Approach

Abstract
Foundational to our learning-centric paradigm is the notion of mental models. We recognize that students develop mental models that represent their understanding of subject matter. These mental models differ from person to person, especially among people from different engineering disciplines and from different universities. In Fall 2012, we received IRB approval to investigate the impact of individual mental models on the shared (team) mental model (and vice versa), how individual mental models change over the course of a semester and how students with different mental models prepare themselves to learn how to learn in an increasingly wired, interconnected and culturally diverse world. In this paper, we describe the salient features of AME5740 Designing for Open Innovation and our initial findings from the study.

1 Frame of reference
With increasing globalization and 21st century trends such as the commoditization of technology, individuals are required to continuously refresh and adapt their competencies and keep their knowledge current. It is well documented that the changing environment and the diverse learning needs of individuals demand a change in the existing paradigm of engineering education. What is needed is a more flexible, learner-centric paradigm that, among other things, instills in individuals the habit of becoming self-directed, life-long learners.

Additionally, teams are a critical and essential part in most organisations and companies because they combine different views, multiple skills, diverse experiences, analytical judgments and rich knowledge. Consequently, research in teams and learning has been a continuous endeavour in various scientific areas for more than thirty years. However, the concepts of team and group are often used interchangeably. Therefore, in this paper we define a team as follows: a distinguishable set of two or more individuals who interact dynamically, interdependently, and adaptively toward a common and valid goal, who have each been assigned specific roles or functions to perform and who have a limited life span of membership [1].

Over the past few years, at the University of Oklahoma, a graduate course titled AME5740 Designing for Open Innovation has been designed, course content and assignments developed and a learner centric paradigm instantiated. Different facets of this course have been described in several publications – most recently in [2], [3]. In these papers, the authors explore the key question: How can we foster learning how to learn and develop competencies? In this paper we document our initial findings as to how far we have succeeded in facilitating students learning how to learn and develop competencies within this course.

This paper is organized as follows. In Section 2 we introduce a theoretical overview on teams and team-based learning. In Section 3, we cover the salient features of AME5740 Designing for Open Innovation with the assignments being summarized in the two appendices. In Sections 4 and 5, we outline the organization of our study and the research questions followed
by a description of the research method. The initial findings are summarized in Section 6 which is followed by a short discussion in Section 7. We end this paper with some closing remarks in Section 7.

2 Teams and team-based learning
A successful team typically possesses an informational advantage over individuals [4]. However, not all teams are able to take full advantage of these benefits. Some teams may even fail their tasks. Therefore, a considerable amount of research has been undertaken to examine the question why certain teams are more effective than others [5–8]. Overall, shared mental models are regarded as a significant factor for successful team processes and team performance [9], [10].

2.1 Shared mental models
A central concept of cognitive psychology is that individuals construct mental models in order to understand and explain experiences and events, process information and solve complex problems [11–13]. More precisely, the theory of mental models is based on the assumption that cognitive processing takes place in the use of mental representations in which individuals organise symbols or representations of experience or thought in such a way that they effect a systematic representation of this experience or thought, as a means of understanding it – or explaining it to others [12]. Hence, in order to create subjective plausibility the individual constructs an internal model that both integrates the relevant semantic knowledge and meets the perceived requirements of the situation [11], [14]. This internal model is referred to as an individual mental model (IMM).

Shared mental models (SMM) are denoted as a shared representation of a team that includes overlapping domain and task knowledge, skills, attitudes, objectives, processes, components, communication, coordination, adaption roles, relationships, behaviour patterns and interactions [15–17]. It is evident that if team members share similar mental models they are more effective in their teamwork and perform better [1], [10], [18–20]. For example, Lim and Klein [21] found that shared task knowledge and shared team knowledge were valid predictors for team performance and success. Similar results regarding the influence of shared task and team knowledge on team performance were found in replicated studies using flight simulators in laboratory settings [22], [23].

Although other authors have highlighted different operationalisations of SMM [24], our empirical investigation is based on an extended cognitive perspective of SMM. In Figure 1, we illustrate the interaction of IMM and SMM and its influence on team processes and team performance. The IMM of each team member integrates complex knowledge structures on declarative, procedural and metacognitive levels [25–27]. The overlap of the IMMs is regarded as SMM. Cannon-Bowers and Salas [18] identify two major components of SMM: task-related components and team-related components. As every team member shares a certain amount of those components it is therefore possible for a team to develop a collective understanding of tasks, conditions and requirements that are needed to cope with the problem to be solved. However, this overlap is a result of complex interrelationships between individual declarative, procedural and metacognitive knowledge as well as shared task and team related knowledge [18]. Team processes describe the transformation of all inputs through social interaction among team members into results, such as critical perspectives, new ideas, decisions or material objects. Finally, the result of all actions reflect the team performance [21], [22], [28], [29].
3 Salient features – AME5740 Designing for Open Innovation

The orchestration of this course is different to typical graduate courses in engineering. Firstly, the concept of Senge’s Learning Organization [30] was emphasized throughout the lectures and the assignments. This allowed a fluent development of both competencies and learning objectives. Secondly, each lecture was focused one or more questions for the day; see Section 3.3. These questions provided the rationale for covering the material on a particular day. When viewed at the end of the semester the questions represented a framework within which the course was orchestrated and a means for the students to frame their Semester Learning Essays.

3.1 Course organization

The relationship between the team organization and the course content is displayed in Figure 2. The course content is centered on deliverables and lectures that are associated with dilemmas involving economy, society and environment. Each assignment and deliverable which was addressed in the class content was designed to support the team organization. Early in the semester students were given the question for semester (Q4S) in the context of their semester competencies they wished to develop along with their supporting learning objectives; see Figure 14. There were lectures focused on higher-level topics related to “learning how to learn” along with content-based lectures focusing on bridging fuels and the wired and connected world of 2030. Lectures on tools to help frame and answer the Q4S through dilemma identification and management were also included. Finally, students reflected upon their semester learning through
a semester learning essay. All of the class content was focused on dilemmas resulting from economical, sociological and environmental aspects that arise in energy policy and bridging fuels. The assignments are reproduced in the two appendices.

Figure 2. Relationship between the class content and the team organization

The team organization was supported through the class content and the assignments developed around this content. There were several levels of the team organization. Firstly, there were assignments early on in the semester designed for students to identify the competencies that they wished to develop throughout the semester (A0, A1, A2). This allowed for individual learning. Next, there were assignments that allowed students to get experience working in teams (A2, A3). Groups of three formed at the university level. This level of team organization allowed group learning. The assignments were designed to support collective learning through the use of technologies to address the geographical differences (A3, A4). The Q4S was finally a compilation of A3 and A4 and the answer was compiled and submitted by each team. One of the unique aspects of this course was the collaborative structure in which students worked in team settings in order to answer the Q4S. Students were asked to identify competencies needed to be successful at creating value in a culturally diverse, distributed engineering world. These students developed these competencies by completing various assignments designed to collaboratively answer the Q4S. Students completed these assignments individually and collaborative in teams.
3.2 Learning organization
According to Senge [30], a Learning Organization is “an organization that facilitates the learning of all its members and consciously transforms itself and its context”. A learning organization exhibits five main characteristics: (1) systems thinking, (2) personal mastery, (3) mental models, (4) a shared vision, and (5) team learning. Throughout this course assignments were framed with these five disciplines.

We used Senge’s framework to create a learning community made up of individuals, teams and cross-teams within the class. In our approach, systems-thinking is achieved by posing a high-level question (Q4S) for the students to be addressed by scaffolded activities and assignments throughout the semester. Personal mastery is achieved by students defining and striving to achieve personal learning objectives that are tied to the development of competencies. At the start of the course, in Assignment 0, the students are asked to identify the competencies that they wish to achieve as a result of taking this course; see Appendix 1. The competencies are classified as white space competencies, meta-competencies and competencies. The competencies are supported by learning objectives. The learning objectives are anchored in Bloom’s Taxonomy [31], [32]. For one student, the submissions from the start and end of the semesters are shown in Figures 3 and 14, respectively.

![Meta-Competencies Diagram]

Figure 3. Example of competencies and learning objectives at start of semester

Competencies are the result of integrative learning experiences in which skills, abilities, and knowledge interact to form bundles that have currency in relation to the task for which they are assembled [33]. On the other hand, learning objectives embody cognitive skills that students wish to attain so that they become competent in performing the task. Learning objectives are defined in terms of the six learning domains in Bloom’s taxonomy (knowledge, comprehension, application,
analysis, synthesis, and evaluation) [31]. In the examples of learning objectives, the keywords from Bloom’s taxonomy are underlined. The authors are aware of the revision of Bloom’s taxonomy and changes (remember, understand, apply, analyze, evaluate, create) [32]. After reflection, they have consciously chosen to use the older version for this course in engineering.

The questions that students were asked during the first lecture were: “What competencies do you need to develop to be successful at addressing dilemmas associated with the realization of complex, sustainable, socio-techno-eco system in a distributed engineering world?” and “What competencies do you wish to develop in this course so that you are competitive in the world of 2030?”

This required reflection: What competencies do I have? In the context of the world of 2030 what competencies do I need to develop? Based on the competencies that a student wished to develop, he/she defined the learning objectives and related these objectives to the competencies with appropriate justification. For additional information see [3].

3.3 Lecturing with a purpose

Each lecture started with a question for the day (QD). The question for the day was designed to give meaning to each lecture and to frame each lecture with a purpose. In addition, the question for the day made students think about one aspect which was designed to help answer the Q4S. These questions were labeled in sequence in order to identify with the flow of information through the lectures. The QDs for the foundational lectures follow:

<table>
<thead>
<tr>
<th>Lecture 1 – Context</th>
</tr>
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<tbody>
<tr>
<td>QD1 – August 21, 2012: What are the key foundational white space competencies that “tool maker” engineers must have to be able to create value in a wired and interconnected, culturally diverse world?</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Lecture 2 – Competencies, Learning Objectives and A0</th>
</tr>
</thead>
<tbody>
<tr>
<td>QD2 – August 23, 2012: What competencies do you wish to develop to be successful at addressing dilemmas associated with the realization of complex, sustainable, socio-techno-eco system in the wired, interconnected and culturally diverse world of 2030?</td>
</tr>
<tr>
<td>QD3 – August 23, 2012: What are your learning objectives for in this course and how do they relate to the competencies?</td>
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<tr>
<th>Lecture 3 – ORA, Deep Reading, Learning Statements and A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>QD4 – August 28, 2012: How do I create knowledge?</td>
</tr>
<tr>
<td>• By using the Observe-Reflect and Articulate [ORA] construct.</td>
</tr>
<tr>
<td>• Through Deep Reading</td>
</tr>
<tr>
<td>QD5 – August 28, 2012: How do I keep track of my progress in attaining my competencies?</td>
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<tr>
<td>• By writing learning statements in A0 Item 9.</td>
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<tr>
<th>Lecture 4 – A Learning Organization / Community</th>
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<tbody>
<tr>
<td>QD6 – August 30, 2012: What is a Learning Organization?</td>
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<tr>
<td>QD7 – August 30, 2012: What is the relevance of the learning organization construct to this course?</td>
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<tr>
<th>Lecture 5 – Sustainability / Identifying Dilemmas</th>
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<tbody>
<tr>
<td>QD8 – September 4, 2012: What is a dilemma?</td>
</tr>
<tr>
<td>QD9 – September 4, 2012: What is the sustainability pyramid?</td>
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<tr>
<td>QD10 – September 4, 2012: How do I identify a dilemma?</td>
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<tr>
<td>QD11 – September 06, 2012: What are the key characteristics of my world of 2030?</td>
</tr>
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3.4 Assignments to scaffold learning and team formation
One of the main differences between this course and that of a traditional nature is how the assignments were used to scaffold student learning and team formation. In this course, learning was achieved at three levels: individual learning, team learning, and learning from each other in the AME5740 community. This structure was systematically developed using the assignments. Initially, the assignments were focused on the individual to help each student identify his/her own learning objectives. The teams were core to developing an answer to the Question for the Semester (Q4S) and an important component of the end of semester deliverables. The details of the assignments are presented in the appendices. In addition to the team answer to the Q4S, at the end of the semester, each student submitted two reports, namely, an end of semester Assignment 0 and a semester learning essay. For details see Appendix II.

4 Research questions and design of study
In Fall 2012, we received IRB approval to investigate the impact of individual mental models on the shared (team) mental model (and vice versa), how individual mental models change over the course of a semester and how students with different mental models prepare themselves to learn how to learn in an increasingly wired, interconnected and culturally diverse world. Overall, this initial study is exploratory and descriptive, rather than prescriptive. Specifically, the study is guided by the theoretical model (see Figure 1) and the following research questions:

1. How do individual mental models change over the course of a semester?
2. How do shared mental models change over the course of a semester?
3. Do individual mental models have an impact on the shared mental model?

In this study, we focused on capturing and interpreting students’ individual and team-based learning processes. Though the findings may not be generalizable, case studies allow researchers to hypothesize and theorize relationships that may otherwise remain covert [25].
4.1 Participants and design

Nine students who enrolled in Fall 2012 in AME 5740 Designing for Open Innovation were invited to participate voluntarily in this study. Based on the response to Assignment 0 and Assignment 1 the course instructor assigned students to teams to work on Assignment 2. Each team had three students. The demographics are as follows:

Team Alpha: Doctoral student (industrial engineering, Iranian, female), exchange student (aerospace engineering, German, male), undergraduate (mechanical engineering, permanent resident of Iranian extraction, female).

Team Beta: Doctoral student (mechanical engineer, working full time in industry, US citizen, male), MS student (aerospace engineer, working full time in industry, US citizen, male), undergraduate (industrial engineer, working full time in industry, US citizen, male).

Team Gamma: MS student (mechanical engineer, working full time in industry, US citizen, male), MS student (mechanical engineering, Indian, male), MS student (industrial engineering, Indian, male).

The final sample for this study consisted of students from team Alpha (1 male and 2 females ages 23 - 32). All three participants described themselves as non-Hispanic white and two participants declared themselves as international students.

The experiment included assessment of learner characteristics ($O_{LCH}$), individual mental models ($O_{IMM}$), shared mental models ($O_{SMM}$), team process ($O_{TPR}$), and team performance ($O_{TPE}$) evaluation at significant course deliverables during the semester that are represented as $X_1$, $X_2$, and $X_3$; see Figure 4a. $O_{LCH}$ and $O_{IMM}$ are assessed at the start of the semester to get a base-line. $O_{IMM}$, $O_{SMM}$, $O_{TPR}$ and $O_{TPE}$ are then assessed from assignments and deliverables to determine change in students’ individual and team learning process. The relationship between the assignments and the evaluations is illustrated in Figure 4b. For 350 word essays on Individual Learning and Evaluation and Team Learning and Evaluation see Appendices I and II.

Figure 4. (a) Longitudinal research design and (b) Assignment and evaluation timeline
4.2 Instruments

Individual mental model assessment
The individual mental model assessment focused on declarative, procedural, and metacognitive knowledge. Three prompts asked the participants to write three paragraphs with at least 350 words each.

Shared mental model assessment
The shared mental model assessment focused on the participant’s contribution to the team and the other team members’ contribution to the team. Two prompts asked the participants to write two paragraphs with at least 350 words each.

Team assessment and diagnostic measure
The TADM (team assessment and diagnostic measure) instrument measures team-related knowledge [26]. TADM consists of 17 items forming six factors (team knowledge, communication, attitudes, dynamics and interactions, resources and environment, satisfaction/frustration). The questions were answered on a five-point Likert scale (1= strongly disagree; 2 = disagree; 3 = not sure; 4 = agree; 5 = strongly agree).

Attitudes towards engineering
The 44 questions were answered on a five-point Likert scale (1= strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree).

Self-concept
The participant’s self-concept was measured with the confidence scale [27] consisting of 8 items which were answered on a five-point Likert scale (Cronbach’s alpha = 0.87). Four items focused on the participant’s confidence for performing in the course and four items focused on their confidence for performing on their first engineering job after graduation.

4.3 Procedure
At the start of the semester, demographic data (5 minutes), learner characteristics (beliefs, self-concept; 10 minutes), and a pre-assessment of attitudes towards engineering (15 minutes) were collected. During the semester, three waves of data collection were administered as follows: Individual mental model (3 paragraphs – 350 words – focusing on declarative, procedural, and metacognitive knowledge; 30 minutes), shared mental model (2 paragraphs – 350 words – focusing on self and other participant’s contribution to the team; 20 minutes), TADM (team assessment and diagnostic measure; 5 minutes), self-concept (5 minutes). The last wave of data collection additionally included a post-assessment of attitudes towards engineering (15 minutes). For details of the requested paragraphs see highlighted text in Assignments 3 and 4 in Appendix 1 and Item 15 in A0EOS documented in Appendix 11.

4.4 Data analysis
The AKOVIA (Automated Knowledge Visualization and Assessment) tool allows an automated analysis of verbal re-representations [28, 29, 30]. The re-representation process is carried out in multiple stages including several parsing heuristics. The automated analysis generates seven measures including four structural and three semantic measures [28, 31]. The seven measures are quantified as follows: $0 \leq s \leq 1$ (where $s = 0$ is complete exclusion and $s = 1$ is identity). In Table 1 we describe the seven measures.
Recent studies including the AKOVIA analysis functions show a high practicability for multiple research questions and good overall test quality [28, 31, 32, 33]. The reliability scores range from $r = .79$ to $r = .94$ and are tested for the structural and semantic measures separately and across different knowledge domains [34]. Convergent and divergent validity has been tested using several criteria. Ifenthaler [28] reports a validity study using a declarative knowledge test as an outside criterion. The study demonstrates convergent (declarative knowledge correlates significantly with the semantic measure, $r = .355$) and divergent validity (no significant correlation between declarative knowledge and structural measures). Another validation study showed convergent validity among structural (e.g., SFM & GRM, $r = .79$; SFM & STM, $r = .63$; all correlations are significant) and among semantic (e.g., CCM & PPM, $r = .68$, PPM & BSM, $r = .91$; all correlations are significant) measures [34].

**Table 1. Description of the seven AKOVIA measures**

<table>
<thead>
<tr>
<th>Measure [abbreviation] and type</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface matching [SFM]</td>
<td>The surface matching compares the number of vertices within two graphs. It is a simple and easy way to calculate values for surface complexity.</td>
</tr>
<tr>
<td>Structural indicator</td>
<td></td>
</tr>
<tr>
<td>Graphical matching [GRM]</td>
<td>The graphical matching compares the diameters of the spanning trees of the graphs, which is an indicator for the range of conceptual knowledge. It corresponds to structural matching as it is also a measure for structural complexity only.</td>
</tr>
<tr>
<td>Structural indicator</td>
<td></td>
</tr>
<tr>
<td>Structural matching [STM]</td>
<td>The structural matching compares the complete structures of two graphs without regard to their content. This measure is necessary for all hypotheses which make assumptions about general features of structure (e.g. assumptions which state that expert knowledge is structured differently from novice knowledge).</td>
</tr>
<tr>
<td>Structural indicator</td>
<td></td>
</tr>
<tr>
<td>Gamma matching [GAM]</td>
<td>The gamma or density of vertices describes the quotient of terms per vertex within a graph. Since both graphs which connect every term with each other term (everything with everything) and graphs which only connect pairs of terms can be considered weak models, a medium density is expected for most good working models.</td>
</tr>
<tr>
<td>Structural indicator</td>
<td></td>
</tr>
<tr>
<td>Concept matching [CCM]</td>
<td>Concept matching compares the sets of concepts (vertices) within a graph to determine the use of terms. This measure is especially important for different groups which operate in the same domain (e.g. use the same textbook). It determines differences in language use between the models.</td>
</tr>
<tr>
<td>Semantic indicator</td>
<td></td>
</tr>
<tr>
<td>Propositional matching [PPM]</td>
<td>The propositional matching value compares only fully identical propositions between two graphs. It is a good measure for quantifying semantic similarity between two graphs.</td>
</tr>
<tr>
<td>Semantic indicator</td>
<td></td>
</tr>
</tbody>
</table>
Balanced semantic matching

The balanced semantic matching is the quotient of propositional matching and concept matching. Especially when both indices are being interpreted, balanced propositional matching should be preferred over propositional matching.

5 Initial findings
5.1 Research question 1 - individual mental models

How do individual mental models change over the course of a semester?

In order to describe the diversity and variability of students’ mental model, we used the automated visualization function of AKOVIA [34]. The visualization function creates an association net based on the semantic text produced by the students at various points during the semester in response to the assignments.

In Figures 5 and 6 we show the initial representations of the students’ declarative knowledge.

Figure 5. AKOVIA representation of student’s MF06F declarative knowledge at beginning of the semester
Clearly, the most important concepts used by the students focused on the tools introduced during the first class meetings as well as the collaborative setting of the course. The red lines indicate strong association between concepts and blue lines indicate weak associations between concepts.

In Figures 7 and 8 we illustrate the representations of the students’ declarative knowledge at a later stage of the semester. Here, a clear shift can be identified towards a more elaborate understanding of the subject domain of the course. However, some concepts (and propositions, i.e., concept – link - concept) are not well connected to the overall understanding of the student (e.g., order, requirements, organizations, techniques).

Overall, students gained declarative, procedural, and metacognitive knowledge over the course of the semester. Also, there was a clear shift from basic concepts linked to tools used for the course to more elaborated concepts linked to the problem’s domain of the course. However, the strongest gain was found on the declarative knowledge level (see Figures 5, 6, 7, 8). Additional descriptive analyses of the quantitative AKOVIA measures suggest that students have moved forward significantly in collaborative, team dynamics, communication, etc. which are metacognitive knowledge (e.g., Figure 9).
Figure 7. AKOVIA representation of student’s ID04F declarative knowledge at a later stage of the semester

Figure 8. AKOVIA representation of student’s MF06F declarative knowledge at a later stage of the semester
5.2 Research question 2 - shared mental models

How do shared mental models change over the course of a semester?

To perform the analysis various individual responses are aggregated into a shared common knowledge representation, using the aggregation function of the AKOVIA technology. The aggregated representation is developed based on common knowledge the individuals share. In Figures 10, 11 and 12 we illustrate how the shared mental models change over the course of the semester. Clearly, a shift from being aware of meta-competencies earlier in the course, and then developing these competencies at a higher level of cognition, along with a more domain oriented declarative knowledge can be seen (e.g., alternatives, fuel, economy, etc.).
Figure 10. AKOVIA aggregated representation of shared declarative knowledge at beginning of the semester

Figure 11. AKOVIA aggregated representation of shared declarative knowledge at middle of the semester
5.3 Research question 3 - impact of individual mental models in shared mental model

Do individual mental models have an impact on the shared mental model?

Using the quantitative comparison measures of AKOVIA, we calculated similarities between the aggregated shared mental models and the individual mental models. Overall, we found a variation of individual influence (mental model) on the shared mental model. For the declarative knowledge, we found equal influence of all students at measurement point one (see Table 2). The contribution of the individuals to the shared knowledge gained in the middle of the semester. However, at the end of the semester we found that student MF06F contributed 80% of declarative knowledge to the shared mental model while student MM07F only contributed 23% to the shared mental model.

<table>
<thead>
<tr>
<th>Time of semester</th>
<th>Student</th>
<th>Declarative knowledge</th>
<th>Procedural knowledge</th>
<th>Metacognitive knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>MF06F</td>
<td>0.43</td>
<td>0.69</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>MM07F</td>
<td>0.45</td>
<td>0.50</td>
<td>0.83</td>
</tr>
<tr>
<td>Middle</td>
<td>MF06F</td>
<td>0.68</td>
<td>0.48</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>MM07F</td>
<td>0.62</td>
<td>0.67</td>
<td>0.30</td>
</tr>
<tr>
<td>End</td>
<td>MF06F</td>
<td>0.80</td>
<td>0.54</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>MM07F</td>
<td>0.23</td>
<td>0.50</td>
<td>0.12</td>
</tr>
</tbody>
</table>
On procedural knowledge, we found equal contribution of all students on the shared mental model throughout the semester. However, on metacognitive knowledge we found a major contribution of student MF06F on the shared mental model (except for the first measurement point, see Table 2).

6 Discussion
Typically, graduate engineering design courses are a continuation of the content and structure found in undergraduate courses. In our opinion, the structure of graduate engineering courses need to be designed to allow students learn how to be independent thinkers and to take charge of their own learning. With globalization, courses offered in the traditional format do not always prepare individuals to be competitive, and consequently may have little value or relevance to students after they graduate. Hence, we have advocated the mass customization of courses [35].

Our approach is focused on students developing competencies needed in a world in which change is the order of the day [2], [3]. In Figure 13, we display the differences between our approach and the traditional approach found in many engineering programs. The restructuring of this design course has transformed the hierarchical structure of a traditional course into one that facilitates collective learning. To address these differences, students develop competencies by using a method which fosters learning how to learn by placing students in a collaborative environment, which many will experience in academia and industry once they graduate. We focus on students learning how to learn by providing them with an opportunity to learn how to identify and manage dilemmas [36–38].

![Figure 13. Key differences between traditional courses and the collective courses approach](image)

By framing this course in the context of Friedman’s The World Is Flat [39] students used this course as a practical application of working in an environment representative of the flat world of 2030. Although this concept was present from the first day of classes, the students were eased into the idea of how to work collaboratively within teams from their own universities. Although Assignment 0 and Assignment 1 were completed by each student independently; this ensured that
students already had an idea of what competencies and learning objectives they wished to develop individually by completing collaborative assignments. In doing Assignment 2, students were introduced the concept of collaborative learning by working in teams whose membership was determined by Assignment 1 submissions. To ensure that each member contributed equally, team contracts anchored in the learning organization construct were required in Assignment 2.

Assignments that had the potential to add value to the learning of others were shared as “best practices” with the entire class. Often “best practices” from former students of the course were also discussed in class or presented on the course website. This aspect of the presented approach enabled team-based and collective learning; students learn from and about each other, get inspired and can build on others work to develop new knowledge. A positive side effect is also the incentive to be recognized as the author of a “best practice” in the full knowledge that it will be read by others in the class.

7 Closing remarks
Our learner-centric paradigm is anchored in three constructs, namely, mass customization, learning organization with a team-based focus and Bloom’s taxonomy. Different facets of this course have been described in several publications, for example, [2], [3], [35]. The initial results of our study suggest that it is worth to follow this line of investigation in a larger setting in order to gain insight into the complex processes of the learning-dependent development of individual mental models and shared mental models. Teams have many advantages in complex environments [9], [42]. But not all teams are able to take full advantage of those benefits. Some teams may even fail their tasks.

Designing and creating learning environments which empower engineering students to learn how to learn is not an easy task. When students enter learning environments, most learners want quick answers to questions they already have [43], [44]. Thus, students tend to like to be provided with simple recipes and scripts – because they seem to be of more practical value at the time. Our approach to learning environments violates this quasi-need because we aim to bring about conceptual change. Clearly, we need to explore further the effectiveness of scaffolding of learning in this course and we look forward to doing so.

We plan to explore the learner-centric paradigm in an undergraduate engineering design course, namely, AME4163 Principles of Design. The students in the course are required to demonstrate their understanding of design principles by undertaking a design project, in a team environment, through integration of knowledge and information that they have learned throughout the curriculum. We believe that the learning experience in this course can be enhanced by empowering students to identify and develop competencies of their choice to facilitate their learning how to learn.

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References


Appendix 1: Assignments in Fall 2012

Assignment 0: Self Evaluation
This assignment was completed individually. The goal is to help students understand and formalize their mental models. Assignment 0 was considered a pre-assignment which was designed to help students determining the competencies they wished to develop in this course. Although this assignment was the first to be completed it was updated throughout the semester. This assignment was eventually turned in as an end of the semester deliverable. By completing this assignment the students establish their learning objectives and the competencies they wish to develop by taking this course. The students use these goals to track their performance throughout the semester. An example is provided in Figures 3 and 14.

Figure 14. An example of a student’s end of the semester competency development

The students are asked to define their leaning objectives and competencies in the context of Bloom’s Taxonomy. Bloom’s taxonomy is a classification of levels of intellectual behavior important in learning. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation. These six levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. Bloom’s taxonomy provides a systematic way of describing how a learner’s performance grows in complexity when mastering academic tasks. The students are expected to relate to all the six domains of knowledge embodied in Bloom’s Taxonomy. Evaluation is a particularly important construct in Bloom’s Taxonomy. It is foundational to learning how to learn because it helps the students learn how to evaluate their own work.
Assignment 1: Define the world of 2030 through Deep Reading, Observe-Reflect-Articulate (ORA) and Critical Thinking.

This assignment was completed individually. In this assignment, the students were asked to deep read and critically evaluate two articles from Friedman [15, 16]. Some of the questions that the students are asked to answer after reading the articles are: i) what are the key issues facing the world of 2030 as highlighted by the author? ii) how are the issues related to the three aspects of sustainability (social, economic, and environmental)? iii) what are the interdependencies between the issues identified by the author? and iv) what are the relationships between globalization and the issues identified above? The students were also asked to take a first step towards identifying the dilemmas associated with energy policy. The expected outcomes of this assignment were a) vision for the engineering world of 2030, b) a vision of the energy infrastructure in the world of 2030, and c) refined competencies and learning objectives in the context of the world of 2030.

Assignment 2: Collaborative and collective learning

This assignment was completed collaboratively within the students own university and had two primary objectives. The first objective was to experience using a virtual environment to collaborate in a globalized mass-collaborative environment. The second objective was to gain an understanding of the efficacy and limitations inherent in Senge’s Learning Organization. This assignment is used to develop a learning organization within the class using Senge’s concepts. After the students have formalized their mental models in Assignment 0 by identifying what they know and would they would like to achieve, the next step is to create a team vision. As a part of the team vision, the students are asked to identify a) the goals they would like to achieve as a team, b) the tasks that the team needs to carry out, and c) the assignment of responsibilities for completing the tasks. At the end of this assignment, the students develop a team contract that outlines the tasks, responsibilities and overall team outcomes. Team learning is achieved through the process of collectively completing the assignments and answering the Q4S. The deliverable of this assignment was presented as the following:

In the context of a Learning Organization, you are required to propose a plan of action to develop an outline for a paper titled Product Realization Processes for Open innovation in the Globalization 3.0 World.

1. **Personal Mastery**: Introduce yourself. Include the competencies you wish to develop and the supporting learning objectives.

2. **Mental Model**: Review the postings of your team members. Suggest two competencies you wish to develop as a result of doing this assignment.

3. **Team Vision**: Collectively develop a Team Vision that includes a plan of action: What needs to be done, by when and who is responsible, etc. This may involve your having to modify your Mental Model.

4. **Solution**: Propose a solution to the problem, namely, develop an outline for a paper titled Characteristics, Features and Functionalities of IT Infrastructure for Open Innovation.

5. **Individual Learning and Evaluation**: Reflect on your performance in this assignment. Please respond to the following questions in full sentences and write at least 350 words per sub-question.

   a) What are the most significant theoretical concepts (e.g., features of Streamz) you used in completing this assignment? Please elaborate in full sentences and write at least 350 words guided by the following matters of detail:
      - What is the author’s (developer’s) message?
      - What is the purpose of Streamz?
Individual Learning
Reflect on your performance in this assignment. Please respond to the following questions in full sentences and write at least 350 words per sub-question.

a) What are the most significant theoretical concepts (e.g., features from IPcelerate) you used in completing this assignment? Please carefully read your report. Please elaborate in full sentences and write at least 350 words guided by the following matters of detail:
- What are the key elements of the message you have conveyed?
- What technical information and conceptual tools did you find useful in completing this assignment and why?
- How has this assignment helped you develop your competencies and the associated learning objectives?

b) What are the most significant strategies (e.g., search for information) you applied in completing this assignment? Please elaborate in full sentences and write at least 350 words guided by the following matters of detail:
- What strategy worked? Justify.
- What strategy did not work? Justify.
- What strategies do you plan to implement in undertaking the next assignment?

c) What is the state of your overall learning in this course so far? Please elaborate in full sentences and write at least 350 words to include:
- The degree to which you attained your competencies and learning objectives. Please justify.
- What change in strategy is warranted and why.
- The changes (if any) you propose for your personal competencies and associated learning objectives and why.
- The competencies / learning objectives you plan to improve in the next assignment and why.
**Team Learning and Evaluation**

We would like to get an idea about the vision of your team. Please respond to the following questions in full sentences and write at least 350 words per sub-question.

a. What are the most significant theoretical concepts, strategies, and ideas **proposed by you** and adopted by the team?

b. What are the most significant theoretical concepts, strategies, and ideas **proposed by others** that were adopted by the team?

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**End of the Semester Assignment 0**

Assignment 0 was presented to students on the first week of classes. This was a living document which was for students to analyze and develop their competencies and learning objectives. Throughout the semester, students were required to update this document and keep track of their changes and leanings in a journal format. Students then submitted this document at the end of the semester with the other deliverables.

**Semester Learning Essay (SLE)**

The SLE was designed to be a source of reflection and self-assessment. This assignment had a loose structure and students were not given a formal guideline in order to encourage creativity. Students were given the following as a structure:

> “We are looking for Creativity - Thought - Insight … Ability to make the strange familiar and the familiar strange … see and communicate relationships …”

**Analogy/Metaphor:** Choice of metaphor/analogy. Appropriateness. How well it is explained. How creative it is.

**Theme:** Relationship between metaphor and text. Metaphor needs to support text and text needs to add value to the metaphor. Systematic development of theme.

**Related to Course/A0/Competencies/Learning Objectives:** Quotes and citations from earlier essays / best practices. Clearly tied to Assignment 0 and work done throughout the semester. Clearly tied to core-competencies and learning objectives.

**Creativity/Thought/Insight:** Creativity in choice of metaphor and creativity associated with outcomes. Thought – is deep thinking evident? Insight – have observation, reflection, and the articulation of new thoughts taken place?

**Lessons Learnt:** Extent and depth of learning based on ALL work undertaken in this class. Identify lessons learned from lectures, assignments, project, Q4S, etc… To what extent have you achieved the competencies and learning objectives?

**Tie to Assignment 0 Competencies/Learning Objectives:** Critical evaluation of what you set out to achieve in the course and what you really did achieve.

**Self Assessment:** In the context of the previous items, critically evaluate and assign yourself a grade. Justify.”

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**Self Assessment**

In A0EOS, at the end of the semester, the students are called on to reflect on their learning process, the quality of their contributions to the various assignments, the value gained with respect to attaining their individual learning objectives and competencies as well as the value added to the learning organization; see appendix for A0EOS. Finally, based upon this self-reflection, the students are asked to propose a grading scheme for evaluating their own work as well as that of their peers. This includes developing a comprehensive assessment rubric.
showing the categories of work to be assessed along with justifications for the various degrees of achievement, as well as the articulation of the specific grades they believe they have earned. For the purpose of our study, the students were invited to respond to the following Questions 12 d, e, and 15 a, b and c; see Appendix 2.

The answer to the questions for the semester
Each team combined their Assignments 3 and 4 in answering the Q4S and to comment on their individual and team learning. For the purpose of our study the students were invited to submit responses to the two part Question for the Semester:

Part A: We imagine a future in which individuals are empowered to participate in the global value network where geographically distributed people (including engineers) collaboratively develop, build, and test solutions to complex socio-techno-eco engineered systems. Hence, the question for the semester:

“Imagine that you are operating a product creation enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. In the context of social, economic, educational, public policy what are the technology, policy and communication dilemmas associated with which fuel(s) can meet the global energy demand for the next twenty five years while achieving minimum carbon footprint without sacrificing quality of life?”

You will be addressing Q4S Part A in Assignments 2 and 3.

Part B: In recent years new renewable energy technologies are being investigated and the infrastructure to support different renewable sources of energy are being developed. As the world transitions to distributed generation using renewable energy sources, environmental, economical, technological, energy security, scalability, social, cultural, policy, and standard of living factors need to be considered and evaluated in the interim period. To effectively facilitate the transition, the following question need to be addressed:

“Imagine that you are operating an energy systems enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. Your brief is to identify, design, and document the characteristics, features and functionality of the collaboration and communication infrastructure, unified application and the IT infrastructure to support technical collaboration that furthers open innovation involving geographically distributed people (including engineers) collaboratively developing, building, and testing solutions to complex socio-techno-eco engineered systems.”

You will be addressing Q4S Part A in Assignment 3 and using elements of what you learned in Assignment 4 Part B.
OBJECTIVE: Self-Assessment.

DRIVERS / DELIVERABLES

- An answer to the question for the semester. Collaborative work.
- An assessment of the attainment of competencies and learning objectives. A0 End of Semester
- Learning through the semester. Semester Learning Essay.

A0 – END OF SEMESTER

Note: Items 1 through 8 are likely to be different from what you turned in for A0 in the early part of the semester.

Identify Competencies

1. What is your view of the energy infrastructure in 2030? Leverage L01, Friedman, Q4S, learning throughout the semester.
   a. List what you have used from Learning Organization, Friedman, etc.?
   b. Paraphrase in what ways does what you have written connect to the Q4S?

2. Critically evaluate your response in Point 1 and then propose the competencies (in bullet form) that you believe are needed to be a successful energy systems designer in the world of 2030. Justify. Hint: See appropriate slides in Lecture 2, Slides 14 and 15.
   a. What competencies did you use from slides in Lecture 2? Be sure to identify at least one technical competency and at least two meta-competencies.
   b. In the context of what you wrote under Point 1 – assess and justify.

3. Critically evaluate the list in Point 2. This will require you to do a self-inventory of your competencies or lack thereof. List (in bullet form) the 5 competencies you propose to develop in this course.
   a. Compare what you have written under Points 2 and 3.
   b. Assess the improvement in what you have written in Point 3.
   c. Recommend what additional fixes are necessary.

   a. Justify why what you have written in Point 4 is an appropriate response to your paraphrase in Point 1 above.
   b. Recommend improvements.

Identify Learning Objectives

5. Analyze your response to Point 4. Respond to the following question (bullet form): For me to develop the competencies listed in Point 4 what do I need to learn? For each Competency identify the associated Learning Objectives. Note: A Learning Objective must contain the word “learn” in it and include transformative words from Bloom’s Taxonomy + relate to domains of learning. Be sure to highlight the transformative / action words.
   a. Assess whether each of the learning objectives contains the word Learn and transformation words for the appropriate domain of knowledge. If not improve.
b. Assess whether the set of 5 proposed learning objectives span a few domains of learning. If not improve.

6. Classify, refine the list. Prioritize, modify / refine and list your 5 Learning Objectives for this class. Justify.

Relate Pictorially Learning Objectives and Competencies

7. Illustrate (pictorially) the interactions between the competencies and learning objectives identified in Step 4 and Step 6. Comment on the efficacy of the relationship.
   a. Assess whether the Competencies and Learning Objectives are suitably labeled. If not fix.
   b. Assess whether the transformative words in the Learning Objectives are highlighted in the illustration.
   c. Verify whether what you have illustrated is in harmony with what you have written under Point 1 in this evaluation exercise. If not fix.

Value

8. Analyze what you have written in Points 4 and 6 and answer the following questions: What is it you really wish to achieve as a result of taking this course? What have you learned as a result of doing this assignment? Hint: Evaluate Learning Objectives using learning statements; see Lecture 3. Summarize using transformative / action words from Bloom’s Taxonomy. Then, in the context of the learning objectives, evaluate how far you have achieved the competencies; see Slides 14 and 15, Lecture 2.
   a. Assess whether what you have summarized contains transformative words from Bloom’s Taxonomy and the associated competencies. If not fix.

Continuous Improvement

9. In tabular form, record the date and your feelings as you progressed through the semester. Be sure to identify the progress you have made in achieving your learning objectives and competencies every week. Identify the feedback from the instructor / others that you have received and how you have used this feedback to improve your performance in the next assignment.

A0 Completion - Individual

10. Revisit Value = Utility / Time Invested
    Summarize: Assignment 1: Summarize Part 6. Assignments 2 through 6: Value

11. In tabular form, in the context of a learning organization, outline the strategy that you followed in defining your “mental model” for Assignments 2 through 6 AND your contributions to the collaborative assignment.

12. In tabular form summarize your contributions to Assignments 2 through 6 under the following headings:
   a. Themes / ideas proposed by you and adopted by the team …
   b. Themes / ideas proposed by others that were adopted by the team …
    Please respond to the following questions in full sentences and write at least 350 words per sub-question.
   e. What are the most significant theoretical concepts, strategies, and ideas proposed by you and adopted by the team?
   f. What are the most significant theoretical concepts, strategies, and ideas proposed by others that were adopted by the team?

13. In tabular form, please convey how you progressed in attaining your competencies and learning objectives throughout the semester.
14. In graphical format, please convey the degree to which you attained the identified competencies and learning objectives.

15. Analyze what you have written in Steps 10 through 14. Then, critically evaluate your performance (in terms of competencies and learning objectives) throughout the semester; be sure to use action words from Bloom’s taxonomy. Comment on the level of attainment in Step 14, what you would do differently if you had to do it over, and plans for the future. Please respond to the following questions in full sentences and write at least 350 words per sub-question.

d) What are the most significant theoretical concepts (competencies, learning objectives, Bloom’s taxonomy, ORA, learning organization, etc.) you used in completing this course? Please elaborate in full sentences and write at least 350 words.

e) What are the most significant strategies (e.g., team contract, team vision, attention directing tools, etc.) you applied in completing this assignment? Please write at least 350 words guided by the following questions:
   b. What strategy did not work? Justify.
   c. What strategies do you plan to implement in undertaking the next assignment?

f) What is the state of your overall learning in this course? Please elaborate in full sentences and write at least 350 words to include:
   a. The degree to which you attained your competencies and learning objectives. Please justify.
   b. What change in strategy is warranted for the future and why.
   c. The changes (if any) you propose for your personal competencies and associated learning objectives and why.
   d. The competencies / learning objectives you plan to improve in the future and why.

COMMENT: For 15 a, b and c please be sure to write using the learning statement construct.

Self Assessment for A0 End of Semester

16. Reflect on your performance in this class throughout the semester. In tabular form, please suggest a grade for your self in the following categories and justify:\

   b. Degree to which you attained your competencies and learning objectives and why.
   c. Degree to which you learned what you would do differently and why.

17. Overall grade you award yourself for this submission. Not all items are equally important to determine your grade for the course. You may weight items 16a through 16c as shown below.

   - 16a - 30 to 50%
   - 16b – 30 to 50%
   - 16c – 10 to 20%

SEMESTER LEARNING ESSAY

We are looking for Creativity - Thought - Insight … Ability to make the strange familiar and the familiar strange … see and communicate relationships …

18. Analogy/Metaphor

19. Theme

1 Be sure to reference elements of your responses to Items 10 through 15.
Relationship between metaphor and text. Metaphor needs to support text and text needs to add value to the metaphor. Systematic development of theme.

20. Related to course/Assignment 0/Competencies and Learning Objectives
Quotes from earlier essays / best practices.
Clearly tied to Assignment 0 and work done throughout the semester.
Clearly tied to core-competencies and learning objectives.
Critical discussion / evaluation of the achievement of competencies

21. Creativity/Thought/Insight
Creativity in choice of metaphor and creativity associated with outcomes.
Thought … is deep thinking evident?
Insight … have observe, reflect and articulate new thoughts taken place?

22. Presentation
Level of originality wrt cartoons, layout, clip art, etc.

23. Lessons Learned
Extent and depth of learning based on ALL work undertaken in this class.
Identify lessons learned from lectures, assignments, Q4S, etc.
To what extent have the competencies and learning objectives been achieved?

24. Tie-in To Assignment 0
Critical evaluation of what you set out to achieve and what you did indeed achieve.

25. Self Assessment
In the context of Items 18 through 24, critically evaluate and assign yourself a grade. Justify.

GRADE SHEET
Complete the Excel worksheet: Course_Grade_FamilyName
INTEGRATE grade sheet in the A0EOS Word document.