Designing for Open Innovation: Change of Attitudes, Self-Concept, and Team Dynamics in Engineering Education

Dirk Ifenthaler, Zahed Siddique and Farrokh Mistree

Abstract Within Science, Technology, Engineering, Arts, and Mathematics (STEAM) education initiatives, a learner-centric paradigm that instills in individuals the habit of becoming self-directed and life-long learners is a major objective. The implemented instructional framework presented recognizes that students develop mental models that represent their competencies in Engineering. Findings of a case study report the students' change of attitudes, self-concept, and team dynamics while taking the re-designed graduate course. The findings guide the further instructional design of the course and the development of future research projects.

Keywords Engineering · Self-concept · Attitudes · Team · Scaffolding

Introduction

For the past several years, Science, Technology, Engineering, Arts, and Mathematics (STEAM) education initiatives have addressed the concern that the United States is globally losing its competitive edge. It is further argued that individuals are required to continuously refresh and adapt their competencies. It is also well documented that the changing environment of the 21st century and the diverse learning needs of individuals demand a change in the existing paradigm of engineering education (Mistree et al., 2014). What is needed is a flexible, learner-centric paradigm that,

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among other things, instills in individuals the habit of becoming self-directed and life-long learners (Mistree, Panchal, & Schaefer, 2012; Williams & Mistree, 2006).

Over the past few years, at the University of Oklahoma, a graduate course titled AME5303 *Designing for Open Innovation*[1] 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 (Ifenthaler, Mistree, & Siddique, 2014; Mistree, Ifenthaler, & Siddique, 2013; Mistree et al., 2014). In these papers, the authors explore the key question: *How can we foster learning how to learn and develop competencies?*

In this chapter, we document our findings focusing on the students' change of attitudes, self-concept, and team dynamics while taking the re-designed graduate course. Next, we cover the salient features of AME5303 *Designing for Open Innovation.* In the following, we outline the organization of our case study and report and discuss our findings. We end this paper with closing remarks on future developments.

Salient Features—AME5303 Designing for Open Innovation

The orchestration of this course is different to typical graduate courses in engineering. Firstly, the concept of Senge's (1990) Learning Organization was emphasized throughout the lectures and the assignments. This allowed a fluent development of both competencies and learning objectives. Secondly, each lecture was focused on one or more *questions for the day*. 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 essay*.

Course Organization

The relationship between the team organization and the course content is displayed in Fig. 1. 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 the semester* in the context of their semester competencies they wished to develop along with their supporting learning objectives. There were lectures focused on higher-level topics related to "learning how to learn" along with content-based lectures

[1] From 2009 through 2012 the course was offered using a generic (temporary) temporary course number AME5740.

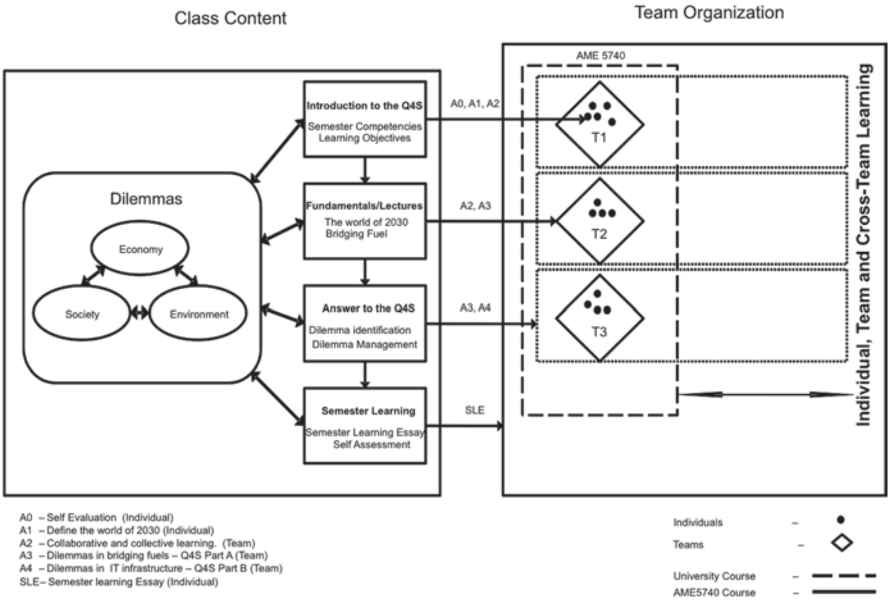

Fig. 1 Overview on the course organization

focusing on bridging fuels and the wired and connected world of 2030. Lectures on tools to help frame and answer the *question for the semester* 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 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. This allowed for individual learning. Next, there were assignments that allowed students to get experience working in teams. Teams of three formed at the university level. This level of team organization allowed team-based learning. The assignments were designed to support collective learning through the use of technologies to address the possible geographical differences. The *question for the semester* was finally a compilation of two assignments 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 *question for the semester*. Students were asked to identify competencies needed to be successful at creating value in a culturally diverse, distributed engineering world. The students developed these competencies by completing various assignments designed to collaboratively answer the *question for the semester.* Students completed these assignments individually and collaboratively in teams.

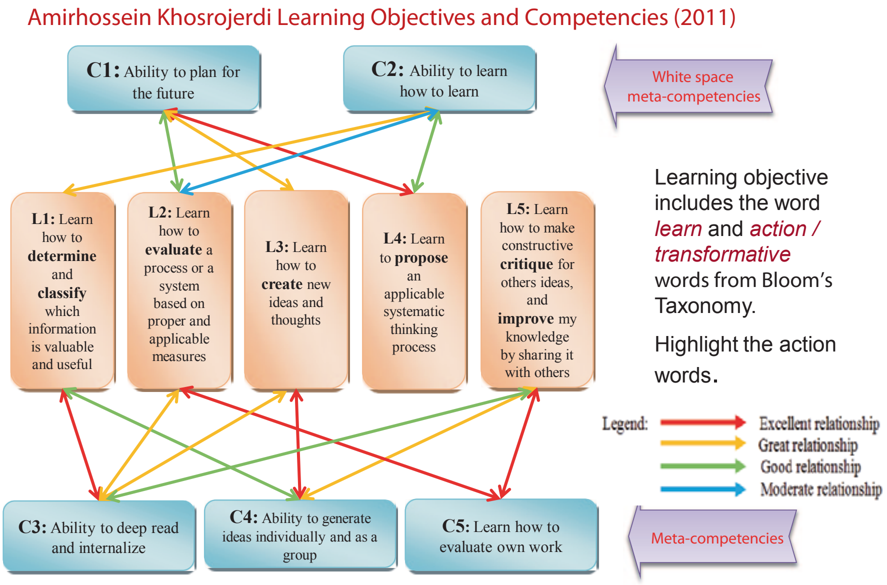

Fig. 2 Examples of student mental models of competencies and learning objectives at the end of the semester

Learning Organization

According to Senge (1990), 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 (1990) 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 (*question for the semester*) 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, the students are asked to identify the competencies that they wish to achieve as a result of taking this course. 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 (Anderson et al., 2001; Bloom, Engelhardt, Furst, Hill, & Krathwohl, 1956; Krathwohl, 2002). The mental model of one students' perception of the relationship of the competencies that he wishes to achieve and the associated learning objectives is illustrated in Fig. 2.

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. On the other hand, learning objectives

Justifications / Introductions	Learning Statements
• Through x (From x, By doing x, ..) • I did not consider x initially • I thought (expected) x before / initially	• I learned y • I realized y • I found out y • I discovered y • I became conscious of y

Fig. 3 Structure of learning statements in keeping with Kolb's model of experiential learning

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) (Bloom et al., 1956). In the example of learning objectives (see Fig. 2), 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) (Anderson et al., 2001). 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.

In keeping with Senge's five main characteristics (disciplines) the team assignments are structured as follows:

1. **System:** Given an assignment.
2. **Personal Mastery:** Internalize the assignment. Develop an approach for tackling it. Post this approach for your colleagues to see.
3. **Mental Model:** Reflect on the progress you have made on your attaining your competencies so far then in the context of your approach for tackling the assignment identify two competencies that you would like to develop by doing this assignment. Post your mental model for review by your teammates.
4. **Team Vision:** Collectively develop a Team Vision that accommodates the proposed Mental Models and includes a plan of action: What needs to be done, by when and who is responsible, etc. Agree on a Team Contract.
5. **Implement Plan of Action:** Be conscious of what you are doing, reflect and identify via *learning statements* what you are taking away and thence achieving your learning objectives and attaining competencies.

Learning statements are anchored in Kolb's Experiential Learning Model, namely that learning is attained through active experimentation-reflective observation and abstract conceptualization-concrete experience. Accordingly, students are required to include in their learning statements justifications/introductions as shown in Fig. 3.

Lecturing with a Purpose

Each lecture started with a *question for the day*. 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 *question for the semester*. These questions were labeled in sequence in order to identify with the flow of information through the lectures. The following list shows examples of the *question for the day* for the foundational lectures.

- 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?
- 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?
- What are some of the changing business paradigms for the world of 2030?
- How will workforce-employer relationships have to change to be more successful in a G3/Open Innovation/Mass Collaborative environment of the year 2030?
- What exactly does "success" mean and how can it be measured?

Assignments to Scaffold Learning and Team Formation

One of the main differences between this course and that of a traditional nature in engineering 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 AME5303 community. This structure was systematically developed using the assignments (see Appendix A for examples). Initially, the assignments were focused on the individual to help each student identify his/her own mental model (Ifenthaler & Seel, 2011, 2013). The teams were core to developing an answer to the *question for the semester* and an important component of the end of semester deliverables. In addition to the team answer to the *question for the semester* at the end of the semester, each student submitted two reports, namely, an *answer to the question for the semester* and a *semester learning essay*. In keeping with the notion of empowering the students to take charge of their learning all students were required to evaluate their own performance in the class and suggest a grade.

Case Study

Research Context

Foundational to our learning-centric paradigm is the notion of mental models. We recognize that students develop mental models that represent their competencies.

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 Fall 2013, based on the initial findings (Ifenthaler et al., 2014), we have modified the course delivery and increased the amount of scaffolding, for example, introduced four exercises that lead into the major assignments, shared past examples of work, provided time for classroom discussion, paused and asked questions, encouraged all students to meet socially and share their work with the entire class.

In this case study we investigate (1) the change of attitudes towards engineering, (2) the student's self-concept, and (3) team dynamics in the course of a semester. Specifically, the following research questions were addressed:

1. How do attitudes towards engineering change over the course of a semester?
2. How does confidence for performing in the course (a) and performing on the first engineering job (b) change over the course of a semester?
3. How do team dynamics change over the course of a semester?

Method

Participants

Nine students who enrolled in Fall 2012 and ten students who enrolled in Fall 2013 in AME5303 *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 final sample for this study consisted of participants from four teams (nine males and three females). The average age of the participants was 24.8 years ($SD = 2.98$). All participants described themselves as non-Hispanic white and six participants declared themselves as international students. Their reported average GPA was 3.44 ($SD = 0.36$).

Instruments

Attitudes Towards Engineering

The 44 questions focusing on attitudes towards engineering 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 (Bandura, 2006) consisting of eight items which were answered on a five-point Likert sale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree; Cronbach's alpha = 0.87). Four items focused on the participant's confidence for performing in the course (CPC) and four items focused on their confidence for performing on their first engineering job after graduation (CPJ).

Team Assessment and Diagnostic Measure

The TADM (team assessment and diagnostic measure) instrument measures team-related knowledge (Johnson, Lee, Lee, & O'Connor, 2007). 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).

Procedure

At the start of the semester, demographic data (5 min), learner characteristics (beliefs, self-concept; 10 min), and a pre-assessment of attitudes towards engineering (15 min) were collected. During the semester, three waves of data collection were administered as follows: Individual mental model (three paragraphs—350 words—focusing on declarative, procedural, and metacognitive knowledge; 30 min), shared mental model (two paragraphs—350 words—focusing on self and other participant's contribution to the team; 20 min), TADM (team assessment and diagnostic measure; 5 min), self-concept (5 min). The last wave of data collection additionally included a post-assessment of attitudes towards engineering (15 min). The individual and shared mental models are not part of this case study, however, more information can be found related work (Ifenthaler, 2014b; Ifenthaler et al., 2014).

Results

Change of Attitudes Towards Engineering

A Wilcoxon Signed-ranks test indicated that the attitudes towards engineering were significantly higher at the end of the semester ($Mdn = 4.01$) than at the beginning of the semester ($Mdn = 3.84$), $Z = 2.64$, $p = 0.008$, $r = 0.86$.

Overall, participants reported high attitudes towards engineering; however, the integrative learning experiences in which they achieved higher competencies during the semester increased their positive attitudes towards engineering.

Change of Confidence

The change of confidence for performing in the course and on the first engineering job was analyzed using Friedman's test. The change of confidence for performing in the course changed significantly over the course of the semester, $\chi 2(4)=9.57$, $p=0.048$. Overall, the confidence for performing in the course significantly increased from the first measurement point ($M=4.08$, $SD=0.64$) to the last measurement point ($M=4.36$, $SD=0.73$).

Additionally, the change of confidence for performing on the first engineering job changed significantly over the course of the semester, $\chi 2(4)=13.12$, $p=0.011$. Overall, the confidence for performing in the course significantly increased from the first measurement point ($M=3.73$, $SD=0.81$) to the last measurement point ($M=4.29$, $SD=0.59$).

Change of Team Dynamics

The change of team dynamics was analyzed using Friedman's test indicating a significant change over the course of four measurement points, $\chi 2(3)=11.72$, $p=0.008$.

Overall, team dynamics increased positively during the course of the semester from $M=3.82$ ($SD=0.45$) at the first measurement point, $M=4.04$ ($SD=0.51$) at the second measurement point, $M=4.17$ ($SD=0.46$) at the third measurement point, and $M=4.32$ ($SD=0.43$) at the forth measurement point.

Disucssion

Currently, there are many initiatives underway to facilitate STEAM competencies. engineering education research is contributing to these initiatives in many ways (King & Magun-Jackson, 2009). Our approach is focused on students developing competencies needed in diverse and quickly evolving world. We argue that advocating the mass customization of courses will allow students to identify and develop selected competencies (Williams & Mistree, 2006).

The reported case study focused on the students' (1) attitudes towards engineering, their (2) self-concept for performing in engineering, and (3) their team dynamics as a key 21st century competence.

First, the findings of this study revealed that the students already had high attitudes towards engineering at the beginning of the semester. Despite the initial high attitudes, the integrative learning experiences during the semester increased their positive attitudes towards engineering. This finding suggests that the course as conceived and implanted shows promise. Second, the findings revealed that the students gained confidence in their ability to take charge of their learning over the course of the semester. This suggests that the students internalized the Bloom's taxonomy construct used to scaffold their learning and gained confidence in their ability to frame problems and prosecute their solution as they will be called on to do when they enter industry or academia. Third the findings revealed that there was a positive increase in team dynamics. This suggests that the students were in harmony with the learning community construct that was used to scaffold individual and team learning.

Implications and Limitations

There is no simple recipe for designing learning environments (Bransford, Brown, & Cocking, 2000) and the design of learning environments will always change in line with the change of educational goals (Gosper & Ifenthaler, 2014; Ifenthaler & Gosper, 2014). In general, the design of STEAM learning environments includes the three simple questions: What competencies have to be learned? How are they learned? How are they assessed? Yet, the design of STEAM learning environments is not simply asking the above stated three questions. Rather, it includes a systematic analysis, planning, development, implementation, and evaluation phases (Gagné, 1965; Merrill, 2007). Further, Bransford et al. (2000) differentiate four perspectives for the design of learning environments. Learner-centered, knowledge-centered, assessment-centered, and community-centered learning environments. It is of course difficult to predict new developments or trends in the domain of the design of STEAM learning environments with any kind of precision, but one thing is certain: They will continue to be dictated to a great extent by the increasing globalization, 21st century trends, and rapid development of information and communication technology (Ifenthaler, 2012).

Especially within STEAM learning environments, creativity is a core competence. Taking into account that creative inventions are understood as artifacts that are new as well as useful and are created by a divergent way of thinking, this requires an iterative process of model-building (Ifenthaler, 2013; Ifenthaler & Seel, 2013). However, the development and successful application of creative inventions often requires quite a lot of time and mental effort due to basic processes of analogical reasoning or internal simulations (Jonassen & Cho, 2008). Therefore, linking educational technology and STEAM learning environments suggests to implement computer-based modeling tools for externalizing the internal simulation process which might take off the learner's cognitive effort and might highlight specific problems when designing creative invention.

Clearly, the presented case study has limitations. Though the findings may not be generalizable, case studies such as this allow us to theorize relationships that may otherwise remain covert. Additionally, the data from two different cohorts may limit the internal validity of the presented case study. However, controlling for effects between the two cohorts did not show any significant differences.

Closing Remarks

In this chapter, we document our findings focusing on the students' change of attitudes, self-concept, and team dynamics while taking the re-designed graduate course.

While implementing this course, we have developed an automated assessment methodology which enables the process oriented analysis of individual mental models and team mental models (Ifenthaler, 2014b). AKOVIA (Automated Knowledge Visualization and Assessment) (Ifenthaler, 2014a) provides just-in-time scaffolding and feedback on semantic and structural aspects of the learner's or team's learning progression and responses to complex problems at all times during the learning process (Ifenthaler, 2009). Such dynamic and timely scaffolds can promote the learner's self-regulated learning and individual characteristics such as metacognition, motivation, beliefs, and attitudes (Ifenthaler et al., 2014). These analysis results could be further utilized to re-design course content, learning objectives, or curricular elements (Ifenthaler & Widanapathirana, 2014).

Clearly, the principal outcome from taking this course is not the test result attained, but a student's ability to *learn how to learn*, which is illustrated through the development of personal competencies in a collaborative learning framework and environment.

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Appendix A

Examples of assignments graduate course titled AME5303 *Designing for Open Innovation*.

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. 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:

   a. What is the author's (developer's) message?
   b. What is the purpose of Streamz?
   c. What is the utility of StreamZ in helping 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:

   a. What strategy worked? Justify.
   b. What strategy did not work? Justify.
   c. 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:

   a. 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.

6. *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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