Studying & Supporting Productive Disciplinary Engagement in STEM Learning Environments

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a Professor of Chemical Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in Chemical Engineering. He currently has research activity in areas related engineering education and is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals. Dr. Koretsky is one of the founding members of the Center for Lifelong STEM Education Research at OSU.

Dr. Susan Bobbitt Nolen, University of Washington

Susan Bobbitt Nolen is a Professor of Learning Sciences & Human Development in the University of Washington's College of Education. She holds a PhD in Educational Psychology from Purdue University. Her research focuses on the development-in-context of motivation to learn in school subjects and the relationships among motivation, engagement, and identity construction. Her current projects include a cross-national collaboration focused on supporting productive disciplinary engagement in complex STEM contexts (including engineering and environmental science): the Science Across Virtual Institutes (SAVI) collaboration with OSU and UTU reported here, sponsored by NSF, the Academy of Finland, and TEKES. Dr. Nolen is a member of the Knowledge-in-Action research group in the UW LIFE Center. In collaboration with teachers and districts, the KIA group is developing engaging, rigorous, project-based AP courses for high school students using a design-based implementation research framework.

Dr. Debra M. Gilbuena, Oregon State University

Debra Gilbuena is a postdoctoral scholar in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. Debra has an M.BA, an M.S, and four years of industrial experience including a position in sensor development. Sensor development is also an area in which she holds a patent. She currently has research focused on student learning in virtual laboratories and the diffusion of educational interventions and practices.

Prof. Erno Lehtinen, University of Turku

ERNO LEHTINEN is professor of education at the University of Turku and is currently holding a five-year Academy Professor position in the Centre for Learning Research of the University of Turku. He has studied early development of mathematical skills, technology-based learning environments, conceptual change in mathematics and science learning, and new forms of expertise in technology rich and networked environments. Email: erno.lehtinen@utu.fi

Prof. Marja Vauras, Centre for Learning Research, University of Turku
Gavin Tierney, University of Washington

Gavin Tierney is a Ph.D. Candidate at the University of Washington. He received his B.A. from The University of Puget Sound and his M.A. from The University of Denver. He is currently a LIFE (Learning in Informal and Formal Environments) Center Research Assistant on The Knowledge In Action Project. He is also an Early Career Researcher, working in collaboration with Oregon State University and The University of Turku in Finland, looking at engagement across virtual and project-based environments. His research focuses on engagement and identity development and the role of designed and alternative environments on these processes. His dissertation focuses on students entering into alternative high schools and explores students' re-engagement in school and re-negotiation of their identities as learners.

Prof. Simone E Volet, Murdoch University, Perth, Australia

Simone Volet is Professor of Educational Psychology at Murdoch University, Perth Australia. Her research takes a combined sociocognitive and situative perspective to the study of learning, motivation and regulation in collaborative learning. Recent theoretical contributions involve the development of a situative framework combining the constructs of social regulation and content processing for analysing productive high-level co-regulation and co-construction of knowledge in STEM collaborative learning environments. She has also contributed to the development of analytical tools for the study of interpersonal regulation in small group learning interactions as they unfold in real time.

Studying & Supporting Productive Disciplinary Engagement in STEM Learning Environments

Introduction

Researchers have described the advantages of complex, realistic, and challenging science, technology, engineering and mathematics (STEM) learning environments that engage students in the practices of STEM disciplines. Benefits include increasing students' likelihood to transfer skills learned during school activities to practice, value of the task, and motivation.[1,2,3] Research teams from four universities are currently studying *productive disciplinary engagement* in these types of learning environments. Productive disciplinary engagement occurs when learners use the discourses and practices of the discipline in authentic tasks in order to "get somewhere" (develop a product, improve a process, gain better understanding of a phenomenon) over time. Productive engagement in meaningful, authentic activity is essential for motivation and progress toward flexible, adaptive expertise in STEM, but learning systems that support it are complex and difficult to scale. Such systems are usually studied and designed in single contexts (e.g., high school environmental science classrooms, engineering design projects), so the knowledge gained, though rich, is difficult to transfer to new settings. Through collaboration among researchers from the United States (Washington and Oregon), Finland, and Australia who study these systems in different curricular, institutional and cultural contexts, we aim to identify unifying themes and develop *generalizable understandings* about supporting engagement and learning in STEM. We focus on group settings in authentic contexts, where students must integrate and flexibly apply concepts and practices.

The research teams use a variety of approaches, including ethnographic (video and audio) records of students and teachers engaged in STEM projects; design-based research on virtual learning environments, material tools and assessment strategies; and controlled field experiments with in-depth process analysis. Ultimately we are trying to answer the following research questions across projects:

- What supports productive disciplinary engagement in advanced, complex STEM learning environments?
- How do these patterns of engagement in complex STEM environments vary by level (high school, university), discipline (engineering, environmental science, veterinary science) and country (US, Finland, Australia)?
- How can findings from these collaborative analyses inform further design of complex STEM learning environments?

Before we can address the above research questions, we first must establish a common understanding of productive disciplinary engagement and develop a system of analysis that enables cross-project investigation. This poster paper presents a summary of our initial progress during the first year of the collaboration and our future plans. During the first year of the collaboration each team has invested effort into building research capacity, coordinating the collaboration, creating working relationships and an understanding of working habits between teams, and exploring the theoretical underpinnings of productive disciplinary engagement.

We begin by discussing our overarching theoretical framework, productive disciplinary engagement. Next we describe the four contexts of the four different research teams represented

(Washington - high school students, Oregon - undergraduate engineering students, Finland - high school science students, Australia - undergraduate veterinary medicine students). We then briefly describe our methods for collaboration and our progress to date. Finally, we conclude with a description of our future plans.

A General Theoretical Framework of Productive Disciplinary Engagement

The research groups described in this paper investigate different educational levels, different students, different teachers, and different cultures. While the contexts are different, an overarching common theory is found in productive disciplinary engagement. Engagement has been defined generally as "active, goal-directed, flexible, constructive, persistent, focused interactions with the social and physical environments."[4] We use Engle & Conant's term *productive disciplinary engagement*[5] to capture the kind of interaction with people and objects likely to result in deep learning of STEM concepts and practices. Engagement is *productive* to the extent that conceptual or practical progress on a problem is made over time. Finally, engagement is disciplinary when students use the discourse and practices of a specific STEM discipline in their work together.

If Engle and Conant's conjecture is accurate, the STEM learning environments that we describe in this paper should foster productive disciplinary engagement by supporting "(a) problematizing subject matter, (b) giving students authority to address such problems, (c) holding students accountable to others and to shared disciplinary norms, and (d) providing students with relevant resources."[6] The pull of the academic setting, however, may make it difficult for students to mentally situate themselves in the disciplinary context. Each learning environment described in this paper includes scaffolding intended to emphasize the "real world" setting.

Within this overarching theory, each collaborator has focused on different aspects and used different, complementary theoretical lenses. In this first year of the collaboration, we focused on articulating these differences and reaching a common, detailed theoretical foundation from which we can investigate productive disciplinary engagement across the different contexts. While additional work is necessary, in this paper we report on our progress to date.

Demanding STEM Learning Environments Across Cultures and Settings

While each team's learning environment centers on project-based and simulation approaches to teaching complex disciplinary practices, they span educational levels (secondary, post-secondary) and scientific disciplines (environmental science, biology, engineering), and national contexts. This diversity provides a unique opportunity to develop potentially transformative and generalizable new understandings of engagement and how to support it in STEM. The secondary contexts include urban, poverty-impacted schools in the US and high schools in Finland with significant numbers of immigrant students. The post-secondary contexts are targeted at capstone students in professional programs (engineering and veterinary) who may be at risk for disengagement from their respective discipline. Our collaboration should yield important insights into increasing the participation and retention of students in STEM. Table 1 provides a summary of the four sites and they are described in more detail below. In the following subsections we provide more detailed descriptions of each of the research team learning environments.

Table 1. Summary of contexts at different research sites.

Site	Student Background and Preparation	Learning Environment Description	Discipline and Student Roles
Washington	High school students enrolled in an advanced placement project-based learning course	Students learn to evaluate problems and design proposed solutions in real-life or simulated environmental projects (reducing their ecological footprint, designing sustainable farms, etc.)	***Discipline:*** environmental science ***Roles:*** citizens, environmental scientists, farmers, and representative at global summit
Oregon	Senior-level undergraduate students that have four years of engineering courses and perhaps an internship or two in engineering	Students are tasked with optimizing a new manufacturing process in the semiconductor industry. The students work on teams and meet with a supervisor to get authorization on their experimental design and to get feedback as the project proceeds. They run experiments on virtual equipment that provides them with real-world data. Students submit their final parameters, a final report, and present their results at the end of the project.	***Discipline:*** chemical, biological, or environmental engineer ***Roles:*** process engineer optimizing a process
Finland	High school students that have had some science and are taking science, but they don't have an entire, role-based curriculum prior to project	A marine scientist laboratory in which students work on teams, submit a research proposal, then engage with a virtual laboratory to carry out experimentation testing the influence of different marine ecosystem factors.	***Discipline:*** science ***Roles:*** doctoral students, different types of scientists (e.g., marine biologists, chemists)
Australia	Second year undergraduate students in a veterinary medicine program. This project provides their first exposure to real-world case material.	The project was a clinical case-based group assignment within a unit on physiology. Students self-select into teams of five or six members and are randomly assigned a real-life clinical case. Each team has a different case and must set their own learning objectives for the project. They present their findings at the end of the six to seven week period.	***Discipline:*** veterinary medicine ***Roles:*** veterinary doctors diagnosing an animal

Washington. At the University of Washington the Washington team's *Knowledge in Action Project* (http://www.edutopia.org/knowledge-in-action-PBL-research) studies learning and engagement in an advanced, project-based environmental science course (AP-PBL Environmental Science) in poverty-impacted urban high schools. With projects as the primary context for learning, students engage in the varied practices of environmental science by taking on the roles of people solving real-world problems: from reducing their family's ecological footprint to taking the role of international representatives negotiating a global climate accord. Student work is sometimes independent but often collaborative, making use of technological tools but interacting face to face. In classrooms of up to 35 students, teachers must support student engagement in unfamiliar disciplinary practices in real time, as students are working to solve complex problems with multiple possible solutions. This requires teachers to have both the adaptive expertise to know how and when to intervene in students' collaborative work without short-circuiting their' disciplinary thinking, and effective tools for formative assessment.

Oregon. At Oregon State University the Oregon's team uses the Virtual Chemical Vapor Deposition (CVD) Project (http://cbee.oregonstate.edu/education/VirtualCVD/) to provide opportunities for student groups to develop and refine solutions to an authentic, industrially situated engineering task through experimentation, analysis, and iteration. This project is described in more detail elsewhere.[7,8,9] Students work in teams on to determine the best (optimal) input parameters to a industrially sized virtual CVD reactor, which deposits thin films on polished silicon wafers. The experiments student teams design are performed virtually, through a computer simulation. Thus, student teams are provided opportunities to practice the complete, iterative cycle of experimental design where they develop and refine their solution based on analysis of experiments. Integral to their success is the ability to develop and operationalize models and identify appropriate strategies. This project has most commonly been delivered as part of the senior-level capstone engineering projects course, but also has been implemented in high school (chemistry, engineering, physics, and biology), community college, engineering cornerstone, and graduate university levels. Senior-level engineering students are the participants of focus in this collaboration.

Finland. At the University of Turku, the Finnish research team employs the Acid Ocean Virtual Laboratory platform (http://www.letstudio.gu.se/studio-3/virtual-marine-scientist/) to help students learn about complex ecological processes, where students become virtual scientists to study the impact of ocean acidification on sea life. Students conduct real, up-to-date climate change experiments, and learn basic principles of experimentation. The data the students analyze are real data gathered by scientists conducting cutting-edge research on global ocean and local Baltic Sea acidification. The study takes place in three high schools in Finland as a part of selective biology and social science courses. Regular curriculum in the target schools generally only includes occasional small projects. Although students learn in the context of the discipline of biology, the whole course in biology is organized as inquiry-based projects and deeply integrated with the environmental policy course in social sciences. The course consists of face-to-face collaborative work and virtual seminars. Students carry out virtual experiments and measure carbon dioxide emissions in their own environments. The biological are then used in environmental policy projects. The point of this work is both to make students familiar with scientific work, and to teach them about the environmental impact of their own activities and in their own society.

Australia. At Murdoch University, the Australian research team's project employs a clinical case-based approach. The project is given within a unit on physiology. Second-year undergraduate veterinary medicine students self-select into groups of five or six members and are randomly assigned a real-life clinical case. When examined by expert veterinarians, some of the cases have multiple appropriate diagnoses, which makes the cases challenging for the undergraduate students. Each group has a different case and must set their own learning objectives for the project. They present their findings at the end of the six to seven week period. The students get feedback and guidance from their instructor in two face-to-face meetings held three to four weeks apart. The instructor often guides students in the formulation of case relevant, concise learning objectives. The meetings also offer a way for the instructor to monitor group progress.

Progress to Date

Working towards answering our research questions, we have made progress in three areas of the collaboration. First, we have articulated our conceptions of and the different ways in which each research team has previously focused on productive disciplinary engagement, i.e., we have made substantial progress towards a common, socially shared (within our collaboration) understanding of productive disciplinary engagement. Second, we have examined our individual learning environments and identified common design characteristics that appear to be key in fostering productive disciplinary engagement, which addresses our first research question. Finally, we have shared our individual methods and performed limited analysis of each other's data in an effort to establish common, cross-team methods for investigating productive disciplinary engagement. With these methods we will be able to evaluate our identified design characteristics and other supports for productive disciplinary engagement in our learning systems, answering our first research question. With these common methods we will also be able to examine the patterns of engagement and how they vary by educational level, discipline, and country, i.e., address our second research question.

Towards A Common Understanding of Productive Disciplinary Engagement

Each of the research teams has used a different lens with which to focus on productive disciplinary engagement. In the following subsections we describe each of the approaches previously explored. We then describe our common path forward.

Washington

From a sociocultural point of view, the Washington research team examines how individuals within student groups negotiate amongst one another to reconcile what the group is trying to accomplish together, i.e., their joint enterprise.[10,11] In addition, this perspective incorporates "figured worlds"[12,13] as a way to examine the social worlds in which students are simultaneously immersed. For example, in one part of the Knowledge-in-Action Project, the Washington team considers how students are immersed in the "school world," where they must satisfy instructor expectations, and the "environmental science world," i.e., the world of environmental scientists. Each world has distinct values and roles, which sometimes conflict. The closer a group's joint enterprise,[11] or common goal, is to what occurs in the workgroups of environmental scientists, the more authentic the activity. Some practices learned in the context of formal schooling may be applicable to a "real-world" setting, but others may be inappropriate or ineffective. In addition to negotiating the joint enterprise, groups negotiate a division of labor and workflow. Individual differences in epistemology, prior knowledge, work habits, and social skills likely result in tensions as groups negotiate the tasks in the project.

Oregon

The Oregon team has also taken a sociocultural point of view. This perspective has combined communities of practice. Lave and Wenger describe a community of practice as "a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice."[14] They describe three dimensions of communities of practice: *mutual engagement* by participants, a *joint enterprise* or goal with some form of mutual accountability, and a *shared repertoire* such as discourse, tools, concepts, and ways of doing things. The Oregon team considers three simultaneous communities of practice: first, the community of chemical engineering, which is disciplined-based; second, the semiconductor industry community which is industry specific; and third, the student community. While each of these communities can be defined separately, they may also overlap, e.g., chemical engineers can work in and participate in the semiconductor industry. The Oregon team has focused on feedback in instructor-student interactions and examined how the instructor-student interactions facilitate productive disciplinary engagement and help students become more fluent with the shared repertoire of a community of practice. An episodes framework has been used as a way to chunk the discourse into thematic units with a clear beginning and end. Within each episode there are up to four stages (surveying, probing, guiding, and confirmation). This framework facilitates identification of specific skills or activities within a community repertoire and highlights how feedback is given regarding these skills or activities. More information regarding the episodes analytical framework can be found elsewhere.[15,16]

Finland

Both the Finnish and the Australian teams combine a cognitive point of view with an emphasis on the importance of social context. Both teams also share theoretical assumptions of metacognitive regulation focusing on how students of a group engage and jointly regulate their cognitive processes to progress towards shared goals.[17] The core idea is to understand metacognitive regulation and communication as students work together in student-led, challenging and collaborative learning systems. A group is a social system of multiple regulating participants and can be considered at both group and individual levels. Therefore, both teams take the perspective that in order to examine metacognitive regulation, it is necessary to consider self- and social regulatory processes as integrated. The Finnish team has used two ways to consider productive disciplinary engagement. First, they have used the concept of socially-shared metacognitive regulation (SSMR), which refers to the students' goal-directed consensual, egalitarian and complementary monitoring and regulation of joint cognitive processes in collaborative learning situations.[18] This approach was utilized reliably to identify different foci (situation model, operation, incidental matter) and functions (activate, confirm, slow, change, stop) of SSMR.[18] Second, they have examined scaffolding and interpersonal regulation when teachers interact with and provide guidance to students and the ways students respond to such scaffolding.[19]

Australia

Building on the same basis as the Finland team, described above, the Australian researchers have investigated social regulation in collaborative learning. This approach combines the constructs of social regulation and content processing as two dimensions of socially-regulated learning.[20] The Australian approach is rooted in living systems theory.[21] Social regulation occurs on a continuum from the individual level to the preferred group level, labeled co-regulation. Content processing occurs on a spectrum from low to high level. In addition, two orientations of cognitive engagement have been identified: task co-production (explicitly satisfying the task with or without conceptual justification) and knowledge co-construction (from gathering information to striving for conceptual understanding).[17]

Task Forces to Explore Two Aspects of Productive Disciplinary Engagement

We have constructed two inter-team task forces to explore different aspects of productive disciplinary engagement. The first task force will focus on the type of activity students engage in and what appears to act as pivot points, shifting their activity from one type to another. The second task force will focus on regulation and roles. Within both task forces, there will also be attention given to how authority, accountability, and opportunities for self-expression contribute to engagement. The two task forces are described in more detail below.

- *Co-construction, Production, and Pivot Point Transitions* – Two orientations of cognitive engagement have been identified: i) task co-production (explicitly satisfying the task with or without conceptual justification) and ii) knowledge co-construction (from gathering information to striving for conceptual understanding). In this area, we will examine these types of engagement and identify the pivot points when students shift from task co-production to knowledge co-construction or vice versa. We seek to identify why students shift from one to the other with the hopes of being able use that information to carefully design and scaffold learning environments to encourage students to engage in co-construction;
- *Regulation and Roles* – Some members of the team have previously examined metacognitive regulation. We will leverage the previous work, and expand to examine metacognitive regulation in the four different educational contexts. In particular, we will integrate the examination of the roles individual students take on in the team setting as they complete their respective projects. We seek to explore how these different roles influence project progress and how the roles relate to teams' regulatory processes.

Identification of Common Design Characteristics

After discussing the learning environments, five common design characteristics were identified. While more research is needed to evaluate the necessity of these characteristics, they appear to be key to fostering productive disciplinary engagement across the different contexts present in this research. The five characteristics are listed and described in the following list:

- Challenging problem - Each of the projects presents a problem challenging enough to require multiple students to be engaged in order to solve it. This level of challenge is seen as required because it promotes collaboration. However, it is important to note the problem should not be so difficult that the students perceive it as unsolvable.
- Iteration - While the students are engaged in a project, the process requires some form of looping or iteration. For example, in projects where students collect dynamic data, the iteration may be in their experimental strategy, i.e., students modify their strategy based upon new data. In projects like the veterinary project, iteration may come in the form of identifying a possible diagnosis, evaluating it against the case information and modifying the proposed diagnosis depending on that evaluation.
- Real world constraints - All of the learning environments include some form of real world constraints, such as limitations on resources, and the types of data available.

- Realistic data - Similar to the real world constraints, realistic data has been identified as a potentially key part of these types of learning environments.
- Roles - The role students play while engaged with the learning environment appears to be crucial. We believe that students should have integral roles that they can identify with and that are clearly part of the discipline they are learning about.

This preliminary list of design characteristics provides a starting point for further investigation.

Towards Common Methods for Investigating Productive Disciplinary Engagement

Along with the different aspects of productive disciplinary engagement that each collaborator has focused, different analytical methods have also been employed. However, in order to address our research questions, we need common methods to facilitate cross-project comparison. The first step to develop common methods was to articulate the methods each team currently uses, assess the overlap between projects and applicability of methods to the other projects. These methods and the types of data collected by each team are summarized in Table 2.

Table 2. summarizes the types of data each research team has collected and the methods used.

Site	**Type of Data - Analytical Methods Used**
Washington	• Surveys administered at the beginning & end of the year; Complex Scenario Test, Advanced Placement Environmental Science Test at the end of the course - hierarchical linear modeling • Student interviews 2-3 times during the course, fishbowls (focus groups), classroom video (student-student and student-instructor interaction) - discourse analysis, content analysis
Finland	• Video recordings of student teams during the project (student-student interaction and student-instructor interaction) - function coding for socially-shared metacognitive regulation, state space grid analysis
Oregon	• Transcribed audio recordings of student teams during the project (student-student interaction and student-instructor interaction), video recordings of student-instructor interaction, student interviews - episodes analysis, discourse analysis, thematic coding • Surveys administered multiple times during the course - discourse analysis, thematic coding, factor analysis
Australia	• Video recordings of student teams during the project (student-student interaction) - coding for cognitive activity and metacognitive regulation

After comparing our methods, we discussed the aspects of productive disciplinary engagement of focus for this collaboration. We are currently in the process of examining these methods and identifying which methods are most appropriate. Some form of discourse analysis with cognitive, metacognitive, and social coding will likely be implemented.

Future Work

As our analysis proceeds and this collaboration evolves, we will further revise and discuss our shared understanding of productive disciplinary engagement and the specific aspects upon which we focus will lead to additional revision of cross-project methods. The currently defined cross-project methods will be tested and will also inform revision. Specific items to be addressed in future work are listed below.

- ***Development of a Baltic Sea Virtual Laboratory* -** In addition to data analysis, we are using our findings to date and the guiding principles of productive disciplinary engagement to design a new learning system. This new virtual laboratory will be able to be used at multiple collaboration sites and will provide a testbed for implementing design recommendations from lessons learned. It will afford iteration on our process of identifying the ways in which our collaborative analyses inform the design of complex STEM learning environments (research question 3). It will be based in part on the Virtual Marine Scientist Laboratory currently used in Finland, but will be geographically specific to Finland with an explicit context of the Baltic Sea. However, the software design will be adaptable to other geographic regions with limited effort.
- ***Inter-team Analysis* -** Analysis will be pursued according to the two task forces described. These task forces have committed to reporting findings in two upcoming conferences.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant Nos. EEC 1261930 and EEC 1261892. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

We would also like to acknowledge all of the individuals who participated in the studies associated with this work. We would also like to acknowledge the people who supported this work with their time and help.

References

1. Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. 2008. Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education*, 97(3), 355–368.
2. Johri, A. and Olds, B. M. (2011), Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences. *Journal of Engineering Education*, 100: 151–185. doi: 10.1002/j.2168-9830.2011.tb00007.x
3. Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn*. National Academy Press Washington, DC.
4. Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology*, 95(1), 148-162, p. 149.
5. Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, 20(4), 399-483.
6. Ibid. p. 399.
7. Koretsky, M. D., Amatore, D., Barnes, C., & Kimura, S. (2006). *The Virtual CVD Learning Platform.* Paper presented at the Frontiers in Education Conference, 36th Annual.
8. Koretsky, M. D., Amatore, D., Barnes, C., & Kimura, S. (2008). Enhancement of student learning in experimental design using a virtual laboratory. *Education*, *IEEE Transactions on,* 51(1), 76–85.
9. Koretsky, M., Kelly, C., & Gummer, E. (2011). Student Perceptions of Learning in the Laboratory: Comparison of Industrially Situated Virtual Laboratories to Capstone Physical Laboratories. *Journal of Engineering Education*, *100*(3), 540-573.

10. Nolen, S. B., Tierney, G., Becherer, K., Cooper, S., Eng, S., & Ward, C. J. (2012). *Engagement in What? The Negotiation of Joint Enterprise in Project-Based Learning.* Paper presented at the The annual meeting of the American Educational Research Association, Vancouver, BC.
11. Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge: Cambridge University Press.
12. Holland, D., Lachicotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds.* Cambridge, MA: Harvard University Press.
13. Jurow, A. S. (2005). Shifting Engagements in Figured Worlds: Middle School Mathematics Students' Participation in an Architectural Design Project. *Journal of the Learning Sciences*, 14(1), 35-67.
14. Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*: Cambridge university press, p. 98
15. Gilbuena, D., Sherrett, B., Gummer, E., & Koretsky, M. D. (2011). Understanding Feedback in an Authentic, Ill-Structured Project through Discourse Analysis: Interaction between Student and Instructor Objectives. *2011 Research in Engineering Education Symposium: Program and Proceedings*, 700-709.
16. Gilbuena, D., Sherrett, B. U., Gummer, E. & Koretsky, M. (2011). *Episodes as a Discourse Analysis Framework to Examine Feedback in an Industrially Situated Virtual Laboratory Project*. Paper presented at the American Society for Engineering Education Annual Conference and Exposition, Vancouver, BC, Canada.
17. Volet, S., Vauras, M., Khosa, D., & Iiskala, T. (2013). Metacognitive regulation in collaborative learning: conceptual developments and methodological contextualizations. In S. Volet & M. Vauras (Eds.), *Interpersonal regulation of learning and motivation: Methodological advances* (pp. 67-101). New York: Routledge.
18. Iiskala, T., Vauras, M., Lehtinen, E., & Salonen, P. (2011). Socially shared metacognition of dyads of pupils in collaborative mathematical problem-solving processes. *Learning and Instruction*, 21, 379-393.
19. Vauras, M., Kinnunen, R., Kajamies, A., & Lehtinen, E. (2013) Interpersonal regulation in instructional interaction: A dynamic systems analysis of scaffolding. In S. Volet & M. Vauras (Eds.) *Interpersonal regulation of learning and motivation. Methodological advances*, pp. 125-146. New perspectives on learning and instruction. NY: Routledge.
20. Volet, S., Summers, M., & Thurman, J. (2009). High-level co-regulation in collaborative learning: how does it emerge and how is it sustained? *Learning and Instruction*, 19, 128-143.
21. Volet, S., Vauras, M., & Salonen, P. (2009). Self- and Social Regulation in Learning Contexts: An Integrative Perspective. *Educational Psychologist*, 44(4), 215-226.