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The Goldilocks Continuum: Making the case for an optimal balance of instructional strategy in mechanical engineering collaborative learning

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Dr. David Jonassen passed away in December 2012; he was a Curators' Professor at the University of Missouri where he taught in the areas of Learning Technologies and Educational Psychology, Dr. Jonassen was the PI of the NSF-Funded "Supporting Collaboration in Engineering Education" that produced the research reported in this article. Over his 40 year career, Dr. Jonassen also taught at the Pennsylvania State University, University of Colorado, the University of Twente in the Netherlands, the University of North Carolina at Greensboro, and Syracuse University. He published 37 books and hundreds of articles, and papers on instructional design, computer-based learning, hypermedia, constructivism, cognitive tools, and problem solving. He has received dozens of awards and was posthumously inducted as a Fellow of the American Educational Research Association. The last 10 years of his life were devoted to the cognitive processes engaged by problem solving, and developing models and methods for supporting those processes during learning, culminating in the book, Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments.

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The Goldilocks Continuum: Seeking an optimal balance of instructional scaffold in mechanical engineering collaborative learning

Introduction

The Accreditation Board for Engineering and Technology (ABET) mandates collaborative competency as a learning outcome for mechanical engineering education. That mandate coupled with the demand for online education urges a rethinking of how educators might best leverage online collaborative tools in mechanical engineering programs.

Collaborative learning is moving engineering education from a traditional model of lectures and exams toward a model of active learning through collaborative experimentation with communicative technologies[1]. Collaborative learning involves a construction of knowledge through social interaction, and computer supported collaborative learning may take place either online or face-to-face through synchronous or asynchronous interactions[2].

Johnson and Johnson[3] identify two relevant gaps in leveraging collaborative tools in education. First, they argue that collaborative tools for education are often chosen with the purpose of supporting prevailing instructional practices rather than transforming instructional strategies. Second, they maintain that current research on collaborative technology has focused on learner achievement while largely ignoring learning theory.

This study describes the experiences of mechanical engineering students assigned to a series of collaborative projects in two semesters of an engineering materials course. Participating students were given two different online collaborative tools, and two different instructional scaffolds for each semester. Participants worked in small groups to solve complex open-ended problems. We interviewed student and faculty participants to ascertain –

1. Which instructional scaffolds and technological affordances do students perceive as helpful when collaborating through online tools?
2. Which instructional scaffolds and technological affordances do engineering instructors perceive as effective for online collaboration?

Presented in this research is a qualitative case study that searches for an optimal balance of instructional scaffolds for online collaborative tools employed in mechanical engineering from a learning perspective. The concept of the Goldilocks continuum represents the natural inclination of humans to move toward the most agreeable or the least disagreeable position; an optimal balance along the continuum.

For sake of this case study, the term *learning* is a student activity that may include explorative strategies, scheduling, or reflection. In contrast, the term *instruction* is a purposeful function of the educator to communicate with learners that often includes scaffolds such as prompting, modeling and phasing task assignments.

Literature Review

There is enduring, convincing evidence of knowledge transformation through collaboration. When compared to individual learning, collaborative learning has been shown to beneficially impact learner achievement, self-efficacy, and relationships among learners[4]. In a review of 168 studies contrasting collaborative, competitive and individual learning on student achievement, collaborative learning reported higher student achievement than competitive or individual learning[5].

Social interaction is a key aspect of knowledge development[6, 9] through which group members transform common knowledge to greater understanding[6]. Cannon-Bowers and Salas[10] maintain that social interaction allows team members to communicate effectively, aid in the diagnosis of problems, and help predict team performance. Notably, group members who interact socially benefit more from collaboration than those who do not[11, 6].

Thompson and Fine[8] identify three outcomes of *socially shared meaning* that describe how collaboration and social interaction are related:

1. Learning tasks may be divided into portions amongst collaborating members, such as a crew of a large ship in which each member has specific task expertise, but often does not fully comprehend their crewmates' tasks.
2. Learning may be held in common by each member, such as those represented by analogous mental models.
3. Learning may be achieved through agreement, such as seeking consensus to determine what issues are agreed/disagreed upon.

Although ABET mandates collaborative learning as an outcome for engineering education, Borrego and Newswander[12] note that the perception of engineers is that they prefer to work alone, independent and unconstrained by the contribution of others. Yet Johnson and Johnson[13] point out that positive interdependence is essential to collaboration. They define positive interdependence as an individual's recognition that their own goals can only be achieved if people they are cooperating with also achieve their goals in the collaborative endeavor.

Thus, to help engineering students learn to collaborate effectively, educators must help them to (1) realize that their personal method of learning is not the only means to insight; (2) learn to respect alternative learning methods used by others; and (3) integrate new methods of learning into the collaboration[12]. Advocates of collaborative learning recommend that instructors create scaffolds that offer students cognitive prompts for processes and models that support interactions between the students, the students and the content, and the students and the instructor[3].

Yet which scaffolds and which tools optimize learner interactions? Must each engineering professor master the nuanced complexity of designing for collaborative learning? Kapur notes that different intended outcomes of collaborative learning require temporally conscious strategies to prompt discussions, either early on in order to maximize group performance[7] or ongoing discussions that lend toward better learning of processes. This is problematic because many engineering instructors have not worked in the engineering industry where collaboration is regularly employed, and as such they lack the ability to design authentic collaborative experiences and environments[14].

A review of current research literature reflects a gap in educator competency for leveraging collaborative learning; specifically how instructional scaffolds are optimized for collaborative learning in engineering programs.

This study seeks a description of experiences for participating engineering students and professors with a specific focus on the instructional scaffolds afforded by collaborative tools. The intent is to identify evidence of collaborative processes that validate affordances of online collaborative tools and instructional scaffolds.

Methods

This research sought to explore a qualitative inquiry of participant descriptions in collaborative learning. Guiding questions included: [1.] Which instructional scaffolds and technological affordances do students perceive as helpful when collaborating through online tools? [2.] How do student perceptions differ from the instructor's perceptions?

The plan is to tell a story in its natural setting; to explore what transpired over two semesters of research involving a single engineering materials course in which multiple online collaborative tools were employed, and one in which the engineering professor welcomed the research team into the learning environment.

Context, Participants and Collaborative Tools

This study took place at a large university in the American Midwest and involved a total of 144 student participants from an undergraduate mechanical engineering materials course over the fall semester of 2011 (FS11) and fall semester of 2012 (FS12). The participants were predominately male with females making up just 6.9 percent of the sample group.

Both FS11 and FS12 were conducted as traditional courses, having 45-minute lectures followed by 2-hour computer lab sessions. The students met face-to-face over the length of both 16-week courses, yet were also offered an online collaborative learning tool to develop their project reports. Students who consented to participate in the study were randomly placed into 4-person groups. FS11 included 16 groups and scheduled six projects over the duration of the semester. FS12 involved just 13 groups and scheduled five projects over the semester. All projects involved an ill-defined problem, specified due dates, and limited guided prompts by the instructor. Researchers offered participants a demonstration of the online collaborative tools.

The course used two tools to support collaboration, initially the PB Works wiki (FS11) and subsequently Google Drive (FS12).

A wiki is a website that allows members to add, edit and delete content in collaboration with other members. The advantage of a wiki is that it allows ongoing documentation for group authoring. Instructors may employ wikis to assess student reflections, concepts, or even feedback on the course instruction.

We selected the Peanut Butter Works wiki (http://PBWorks.com) because it was affordable, perceived as one of the easier wikis to learn, and offered excellent affordances of information storage and sharing. PB wiki allows for revision of documents with trace records of student contributions[15].

We later switched to the second tool based on feedback from instructors and students for the need to support simultaneous editing of artifacts. We then selected the Google Drive Environment for Collaboration (GDEC) because it met the editing requirement and it was a cost-free solution. We also believed that most of the student participants would be at least somewhat familiar with Google online tools and might be more inclined to use a tool with which they may have already had some experience. GDEC is web-based and inherently cross-platform with no additional software required[16].

In FS11 participants in the engineering materials course used the PB wiki tool to collaborate on project problems. Use of PB wiki in the FS11 course was compulsory and interactions were prescriptively structured through prompting questions. Participants had to compile a report on the wiki, and then recompile a hardcopy final report.

In FS12 course participants used GDEC for project problems. Use of GDEC in the FS12 course was optional and interactions were essentially unstructured, unprompted. Only a single hardcopy report was required.

Both PB wiki and GDEC are online cloud-based repositories that afford users synchronous and asynchronous contributions while permitting collaboration via –

- Creating, importing or linking text, spreadsheet and image artifacts
- Editing text, spreadsheet and image artifacts
- Commenting on the margin of contributed artifacts

While all participant groups from the FS11 course were obliged to use the PB wiki tool, almost 70 percent of the participant groups in the FS12 course opted out of the GDEC tool. The remaining groups used GDEC to work collaboratively on the projects and their group reports.

Data Collection

Data were collected through a combination of semi-structured interviews and a focus group interview that combined involved a total of 20 undergraduate engineering students. Interview subjects were neither compulsory nor randomly selected subjects, but instead were volunteers.

The participants were a reasonable reflection of the demographic for engineering students composing the classes for both semesters. That is, predominately young males of Caucasian decent with four young Caucasian females also participating. However the participants did not represent an even distribution.

Table 1 summarizes our data sources. We individually interviewed 16 participants from the FS11 course, one from each of the 16 teams. However we conducted a focus group interview with 4 participants from the FS12 course, representing only two teams: a Google group and non-Google group.

FS11: PB Works Wiki	Individual Interviews for “Groups 1 ~ 6”														
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16 Participants ≈ 20% of Class Population, *Evenly* Distributed															
FS12: Google Drive	Focus Group Interview with “Groups 17 + 18”														
3	1	-	-	-	-	-	-	-	-	-	-	-			
4 Participants ≈ 6% of Class Population, *Unevenly* Distributed															

Table 1: Participant distribution across collaborative groups for Fall 2011 and 2012.

All interviews lasted between 10 and 20 minutes in duration. Most interviews were taped via audio recorder with the exception of the focus group interview, which involved hand-written notes that were annotated to digital text within 24 hours of the interview. Additionally the course instructor was interviewed through ongoing conversations over the duration of the entire two-year study. These interviews were also recorded with hand-written notes.

All interviews took place outside of classroom activity in common areas on campus – a hallway lounge, a conference room, and the focus group took place in a local pizzeria shortly after a very large snowstorm. The interview atmospheres can be described as noisy, somewhat distracting, but informal and relaxed.

Data Analysis

Reliability of data was achieved through a combination of guiding questions developed by the primary researcher, two interviewers, and an independent transcriber.

Triangulation was another concern. This was achieved through a process of a primary coding, member checking, and peer debriefing. Member checking took place via email on the few occasions it was deemed necessary and appropriate. This allowed the student participants to verify researcher understandings of the interview and correct errors or volunteer a further explanation. The intent of such corroboration was to increase the probability that findings would be credible[17].

The initial sweep of data entailed open coding for a descriptive overview. Once saturation was achieved through open coding and themes began to emerge, the various descriptive codes were organized into hierarchical axial codes. This process allowed the researchers to move toward meaningful analysis.

Findings & Discussion

Findings from this study were established through open coded descriptions of interview transcripts, and subsequent axial coding of emergent themes. Two themes emerged from the participant transcripts relevant to the guiding questions:

1. Homogeneous Shared Work vs. Heterogeneous Autonomous Work

2. Technological Affordances of Collaborative Tools

On whole, collaborative methods of learning appear to be somewhat novel to engineering students. Some participants were more comfortable with collaborative learning than others, and the professor recognized the student discomfort in an interview between the two semesters.

> (Collaboration) is such a…it's such a paradigm shift for the students, and I guess we're struggling a little bit with that. You know, the students want answers. They've been so conditioned through all of their engineering education to work toward a correct answer, and so…that's what they've done to work the system – you know, to be successful. When they don't know the answers they become frustrated.
> *Instructor interview, July 30, 2012*

While in general terms the students embraced collaborative learning, not all groups were as successful as the next. The discrepancy may have been due to personality clashes (the group members were selected at random) or it may have been due to collaborative practices within each team, or a combination of both.

> We had difficulty getting the same effort consistently out of every person on the team. One member was incredibly intelligent but had really bad communication skills. And we had one member exactly the opposite. This guy could talk so that everyone understood him and his position – he was convincing, but never knew what he was talking about.
> *Non-Google Group 18, focus group interview, March 7, 2013*

Participants commonly expressed frustration with peers in their group, yet the opposite is also true. Many participants expressed positive working relationships with peers in their collaborative work projects.

> This was the first time I had a positive group experience in my engineering studies. I told my team, "If you can explain it to me simply, or in an analogy then I will understand. And then we can explain it to others." So that was sort of our guide in writing our reports. And this was a really good team to work with.
> *Google Group 17, focus group interview, March 7, 2013*

Homogeneous Shared Work vs. Heterogeneous Autonomous Work

The theme of homogeneous shared work versus heterogeneous autonomous work is pertinent to the first half of our first and second research questions, "Which *instructional scaffolds* do students collaborating through online tools perceive as helpful?" and "Which instructional scaffolds do engineering instructors perceive as effective for online collaboration?"

A **homogeneous group** is comprised of individual members who share similar knowledge, experience and task competency; whereas **heterogeneous groups** are comprised of individual members with vastly different knowledge, experience and task competency[18, 25].

Shared work is described as tasks that are accomplished synchronously with all members focused on the single task at hand. **Autonomous work** is described as tasks that are distributed amongst group members to be accomplished independently. Each member is assigned a unique task that they will explore on behalf of their group, and then report back to the group on findings and solutions at a later date.

Only seven of the twenty participants interviewed favored scaffolds that supported a homogeneous shared approach to collaborative work – although another two more participants stated that their groups eventually worked toward that model through the duration of the semester. The majority of the participants interviewed insisted that their group members preferred to collaborate by distributing the workload and studying independently until it was time to reconvene and assemble the project report. That is, the majority of the participants interviewed express preference for scaffolds that supported heterogeneous autonomous work.

> We got good at distributing those things out from the beginning. For the most part it can be done independently…and then we come together and put stuff together.
> *Wiki Group 2 interview, December 6, 2011*

> We'd make a new page for each topic, and then we'd divide it up. We'd each write our section of the paper, and then we'd put all the sections together in one coherent paper.
> *Wiki Group 15 interview, December 13, 2011*

Here again the professor offers some insight as to why so many of the engineering students preferred to distribute the workload and then address the problems in sections independently instead of as a collective group.

> These students haven't been taught how to do teamwork. For most of them this class is their first opportunity to work on a team for the duration of an entire semester. They don't understand teamwork and there is no understanding of team roles.
> *Instructor interview, July 30, 2012*

Yet a minority of the student participants eased into the work almost effortlessly. These individuals appear to have intuitively and synchronously communicated with group mates to collectively work the problems. And in two cases groups moved from a heterogeneous autonomous work model to a homogeneous shared work model.

> Towards the beginning of the year we would try to break things down to each individual. It became a problem for us because we needed to know what each other were doing, but we were all doing our own little individual thing. That changed. We looked more at each other's work and tried to figure out where we were at all times.
> *Wiki Group 5 interview, December 6, 2011*

Groups that worked synchronously and collectively seem to have bridged that gap of awareness in the status of group members' work. Furthermore they appear to have developed communicative and social skills in so doing.

> J: I like meeting together face-to-face. Sometimes things just get lost in the distance, although sometimes we used the chat in Google.

> K: We'd get on one computer and just knock it out together. One person did the typing and we would all just say, "You should do this" or "You should add this."
> *Google Group 17, focus group interview, March 7, 2013*

The overwhelming trend indicates that student participants appear to favor coming together initially to assess the problem and distribute tasks, then working their assignments independently in isolation from each other. They later reconvene prior to established deadlines in order to compile their answers into a single artifact, in this case a project report.

Through their own descriptions students explain that heterogeneous autonomous work is preferred because they felt it more closely fits autonomous study models they've successfully used in past learning experience to identify the right answer.

> It was difficult to work together in group projects. The effort was to be sure the answers were right. Our reports were compartmentalized. I'd task people or we'd choose different tasks and everyone would write – they'd send me their work to edit.
> *Non-Google Group 18, focus group interview, March 7, 2013*

Yet the professor was more critical of the quality of project reports for those groups who chose to distribute tasks and work autonomously. He appeared frustrated with this collaborative work model.

> Their project reports…they look bad, just terrible! They're obviously massed together and then stapled together. There's really no consistency to them, and that's what we're trying to get them to do – to work together on a written report.
> *Instructor interview, July 30, 2012*

So at least from an outcome focused perspective, we conclude in this study that the engineering professor perceives scaffolds that encourage homogeneous shared work are more effective in terms of online collaboration than scaffolds that support heterogeneous autonomous work.

Curiously, although student participants appear to desire heterogeneous autonomous work scaffolds over homogeneous shared work scaffolds, they report greater satisfactions for grades when collaborative scaffolds include homogeneous shared work.

> We really worked well together. It was the best group working experience I've had in my entire engineering program. Our performance shot straight up the graph." She makes a gesture with her hand, palm flattened, that moves up a steep incline from left to right.
> *Google Group 17, focus group interview, March 7, 2013*

> We were nearly slaughtered on every project. Our first project score was terrible, then we got better, but by the last two projects we were just pushing so hard that our scores got worse again. We struggled with a consistent standard of performance.
> *Non-Google Group 18, focus group interview, March 7, 2013*

This finding begs the question as to whether or not learners always choose the learning model that would best support their learning progress. Empirical research suggests that learners are poor at selecting scaffolds that best suit their needs[19]. However, when learners are offered self-directed learning options that meet their needs, such choices enhance motivation and learning[20]. In our research there was no time scheduled in the engineering course to inform participants of how one scaffold might benefit them more than another.

Technological Affordances of Collaborative Tools

The other half of research questions one and two ask, "Which *technological affordances* do students collaborating through online tools perceive as helpful?" and "Which technological affordances do engineering instructors perceive as effective for online collaboration?" The emergent theme of technological affordances of collaborative tools allows us to explore these questions in some detail.

Groups that worked synchronously appear to prefer the technological affordances of an seamless exchange of information, whereas groups that heterogeneous work valued information storage and sharing most. The PB Works wiki was well accepted by groups who distributed tasks and worked autonomously.

> I think the wiki pages may have helped a little bit…we split up the portions of the report to work on them alone, and upload them to the wiki and then consolidate from there.
> *Wiki Group 1 interview, December 6, 2011*

> It allowed us to share our thoughts. It was really accessible. The wiki was the organization process. I put as much information as I can down, then I can explain. That's just information that you use for the reports, right there.
> *Wiki Group 12 interview, December 13, 2011*

Still, groups who opted to work the project synchronously as a collective group criticized the PB Works wiki. For these participants the data storage affordances of the wiki were offset by the lack of real-time communication and seamless exchange of information that hampered their work and often prompted them to huddle around the same computer.

> It was kind of difficult. The Internet would be slow, plus everyone would be the wiki site at once, so it would get overloaded with people. It would kind of like glitch out.
> *Wiki Group 4 interview, December 6, 2011*

> Other applications allow you to put pictures and documents and tables and things a lot easier than PB Works does. I mean, PB Works is really complicated.
> *Wiki Group 13 interview, December 13, 2011*

Compared to PB wiki, GDEC was well accepted and preferred by groups who worked synchronously. GDEC was perceived as affording realistic communication amongst group members, the simultaneous editing feature receiving the most favorable comments. However, the new edition of GDEC was experiencing problems with simultaneous editing at times.

> K: “We did our work together in Google, even when we met after class to work.”
> J: “Oh yeah, Google would freeze. The screen would freeze.” (She laughs.)
> K: “Yeah, remember when in the library when your terminal froze and it looked completely different than mine?”
> J: “Format was a challenge then because we were seeing different screens and we couldn’t tell which one was right – which was the newest version.
> *Google Group 17, focus group interview, March 7, 2013*

Even with its tendency to freeze due to multiple versions of editing, plus its formatting issues between GDEC documents and Word documents, those groups who opted to collaborate through homogeneous shared work leveraged GDEC effectively.

> We built each report together, at the same time. I think Google definitely did help us because you watch each other as we write. Everyone makes adjustments to the paper at the same time. We could knock out each paper in 2 hours when we worked as a group. It just saves time. We got a 77 percent on our first report, and our grade went up 5 points each for the next four reports. Our last report was like a 97 percent.
> *Google Group 17, focus group interview, March 7, 2013*

The fact remains however that the majority of participants (9 of 13 groups in FS12) who had the option of using GDEC for collaborative learning chose not to do so. GDEC was entirely ignored by teams who collaborated through heterogeneous autonomous work. It may be that these participants simply did not comprehend the affordances of GDEC, or it may be that they simply did not value simultaneous editing.

> We used a huge email chain! We just kept hitting ‘reply’ all the time and it created these huge emails. Someone would put a theory on the subject line and attach web site pages as support. And we’d all jump on and agree or disagree or add new material. Email was simple and reliable. Everyone could check it on our smartphones or whatever we had.
> *Non-Google Group 18, focus group interview, March 7, 2013*

Results Summary

Table 2 conceptually summarizes our results for research questions one and two. An illustrative table captures the emergent trends from qualitative data from interviews with 20 participants and 1 professor. The emergent trend in student preferences for instructional scaffolds is overwhelmingly for those scaffolds that support collaboration through heterogeneous autonomous work models. By contrast, a minority of students plus the professor preferred homogeneous shared work, ostensibly because they perceived better project reports.

The student-preferred means to collaborate through heterogeneous autonomous work includes online collaborative tools that permit information storage and shared access, such as afforded by the PB Works wiki. Than noted, those students who opted to collaborate through homogeneous shared work appear to place far more value in tools with affordances of near real-time communication. For these few groups, GDEC was preferred.

	Collaborative Work Modality	*Technical Affordances of Collaborative Tools*
Dominant Preferences	Heterogeneous Autonomous Work Model (13 Groups)	Information Storage & Access (14 Groups)
Optimal Balance	Homogeneous Shared Work Model (7 Groups, Professor.)	Real-Time Communication (6 Groups)

Table 2: Conceptual representation of results addresses research questions 1 and 2.

Implications & Recommendations

Our research qualitatively explored the articulated experiences of the participants within a collaborative learning environment in engineering education. The effort has been to develop a case study that describes "what happened" through participant stories.

Goldilocks Continuum

At least part of the story involves student participants seeking a semblance of comfort in an online collaborative learning environment. Isolation issues are inherent with online interaction, particularly so with asynchronous communication[21]. Students who do not regularly meet face-to-face report a lack of social pressure to respond to classmates in online courses[22]. Thus, students prefer to collaborate in face-to-face settings due the immediacy of feedback, and because students complain that online collaboration is time-consuming[23].

Overwhelmingly participants of this study sought approaches to collaboration that more closely resembled behaviors associated with past success in traditional engineering courses. Specifically 13 of 20 participants described a process of coming together as a group to identify the problem, then separating tasks assigned independently, and later reconvening to assemble the completed tasks into a single report.

In contrast the residual 7 of 20 participants described an experience of remaining together throughout the project to collectively address the problems, synchronize solutions, and develop the project report jointly.

Participants appear to have sought out a balance between the instructional scaffolds, the technological affordances of the online collaborative tool, and their own work preferences. They leveraged the technology to suit their preferences. Such a balance might be explained as positioned along the Goldilocks continuum. Technology and scaffolds that include too much content may overwhelm collaborative discussion. On the other hand, technology and scaffolds that include too little content results in insufficient information to base a decision[24]. Unless compelled to do otherwise, participants naturally sought an optimal position along the Goldilocks continuum.

Authentic and Effective Scaffolds

Heterogeneous collaborative groups include teammates with unique and specialized task competency[18]. In such cases it is both effective and authentic to divide tasks amongst the various teammates with the appropriate competency[8].

However in the case of undergraduate engineering students, the collaborative group is comprised of homogeneous members. That is, the student participants of this study were remarkably similar in their engineering experience and competency. In such cases it is more practical that learning is achieved through shared agreement, such as seeking consensus on knowledge that is held in common[8].

It is curious then that the engineering students in our research tended toward heterogeneous autonomous work in the collaborative learning environment. The implication appears to be that engineering students will attempt to retain the comfort zone of past educational success in traditional lecture-based classroom until they develop successful experiences in collaborative learning environments.

To that effect, scaffolds which support a homogeneous shared work model offer more authentic and more effective design for collaborative learning in science, technology and mathematics classrooms. In education, homogenous teams tend to function more collaboratively, work toward resolutions, and produce higher work quality than heterogeneous teams[25].

Limitations of Study

We had intended to capture the descriptions of engineering students as they worked in collaborative groups through multiple, ill-structured projects over the course of a semester. Bear in mind that firstly this research involved participants from an undergraduate mechanical engineering program at a large university. As such, any generalizations to other schools, programs or disciplines are justly called into question.

Secondly, only two online collaborative tools are presented in this study, PB wiki and GDEC. It is not our intention to make sweeping generalizations regarding other online collaborative tools. Such claims should be viewed with discrimination.

Thirdly, the focus of this study presents findings related to student collaboration and not necessarily to student performance measures. This research involves post hoc reflections on collaborative learning activities. Participants were asked to share critical incidents in order to cognitively identify strategies implemented for collaborative tools, negotiated tasks and meaning. This paper makes no attempt to quantify specific knowledge or to specify quantifiable contributions to collaboration. Additionally, it is entirely possible that learning took place that simply was not externalized by the participants. Thus a description of participant experiences is all that is being offered.

Recommendations for Future Research

In future research it would be desirable to work with entirely online courses where students do not have the opportunity to meet f2f and thus have more of a real need for using these collaborative tools. This would allow us to conduct research on collaborative learning in a setting where the motivation for using the tools is more authentic. As more and more coursework in science, technology and mathematics moves toward online education it will become increasingly vital that educators understand the implications for instructional design that leverages collaboration.

One area identified as a gap in the literature includes the lack of exploration into cost-benefit analysis of collaborative work in engineering education[12]. Although a relatively minor theme in our research, this topic emerged through interviews with the professor as well as with the student participants. It is possible that a cost-benefit analysis might offer insight as to why engineering students more commonly opt for a heterogeneous autonomous work model over the homogeneous shared model.

Conclusions

This research suggests the preference of a homogeneous shared model of collaboration for engineering education over the far more common student preference of a heterogeneous autonomous model of collaboration. The affordances of two online collaborative tools were explored as means to support both models of collaborative work.

Finally, our research is somewhat unique in that we offer these conclusions from the described qualitative experiences within engineering education. We anticipate that the findings in this study will vindicate the findings of past and future studies.

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