Integrated Design Courses Using BIM as the Technology Platform

Robert Holland[1], John Messner[2], Kevin Parfitt[3], Ute Poerschke[4], Madis Pihlak[5], and Ryan Solnosky[6]

Designers, builders and owners are recognizing the value of having more integration in the design process to facilitate development of more coordinated construction documents, reduction of field changes as well as sustainable designs which consider overall building performance. Building Information Modeling (BIM) is an enabling platform that provides the opportunity to facilitate collaboration and information sharing in design and construction as well as in academic courses. To educate students to contribute to and lead integrated design teams, it is critical that students gain experience during their education in integrated design projects which leverage BIM as a platform for collaboration.

To address this need, we have instituted two new experimental courses into the curriculum at Penn State which focus on providing valuable educational experience in integrated design. The first course is an integrated design studio facilitated through a BIM platform where multidisciplinary teams composed of six students (an architect, landscape architect, structural engineer, mechanical engineer, lighting/electrical engineer, and construction engineer) work together to design, analyze and plan the construction of a building in a semester long studio environment. The second initiative is a two semester capstone design course series in architectural engineering where four students with a structural, mechanical, lighting/electrical, and construction emphasis work together using BIM to perform detailed analyses and design modifications to a building project.

Spring 2010 marked the completion of the second offering of the interdisciplinary BIM Collaborative Studio course and the first offering of the Architectural Engineering IPD / BIM Capstone Project course series. Throughout both of these courses, information was collected regarding the benefits and challenges that the students and faculty have encountered through the implementation of these experimental initiatives. Additional assessment information was also collected which identify the value of the experience and the learning outcomes of the students. The initial offerings of these experimental courses have been very well received by students, faculty and industry participants. This paper will outline the experience gained through the development of these courses along with the assessment data that we have compiled which show the importance of effective collaboration as well as the value for implementing integrated design courses built upon a BIM platform.

---

[1] Associate Professor of Architecture and Architectural Engineering, The Pennsylvania State University, RJHolland@psu.edu

[2] Associate Professor of Architectural Engineering, Director of the Computer Integrated Construction Research Program, The Pennsylvania State University, jmessner@engr.psu.edu

[3] Associate Professor of Architectural Engineering, The Pennsylvania State University, MKPARC@engr.psu.edu

[4] Associate Professor of Architecture, The Pennsylvania State University, uxp10@psu.edu

[5] Associate Professor of Architecture and Landscape Architecture, The Pennsylvania State University, madis-pihlak@psu.edu

[6] Graduate Research Assistant, The Pennsylvania State University, rls5008@psu.edu

1. THE NEED FOR INTEGRATED BIM COLLABORATIVE STUDIOS AND CAPSTONE PROJECTS

Owners, designers and contractors are exploring BIM as a way to change the design and construction process to produce more coordinated buildings at lower life-cycle cost with less risk, shorter project schedules and, potentially, facilitate more sustainable designs. Many companies are actively seeking graduates who can effectively work on these types of projects. To meet these evolving demands of the design and construction processes universities have implemented a variety of courses to expose students to the new BIM software platforms. While BIM is a powerful digital tool, its effectiveness can be severely limited if it is not applied in an efficient and collaborative process. To this end, students should be exposed not only to the new software, but should also have an opportunity to utilize this new software in an integrated collaborative environment to design a project to meet certain specific project performance goals.

Image 1: Student Final Presentation, BIM Collaborative Studio 2010[7]

2. DEVELOPMENT OF AN INTEGRATED BIM COLLABORATIVE STUDIO[8]

The BIM Collaborative Studio involved students and faculty from Architecture, Landscape Architecture and Architectural Engineering in the development of a design studio project which explored BIM technology as a collaborative design tool. The integrated studio focus went beyond just the design and construction disciplines as Dr. Samuel Hunter and his graduate students from Industrial Psychology collaborated to provide valuable input regarding effective teamwork, the development of student feedback mechanisms as well as contribute to Industrial Psychology's study of creative teams.

A major focus of the BIM Collaborative Studio has also been the Integrated Design / Delivery Process (IPD). Thus the BIM Collaborative Studio is providing an opportunity for students to not only become proficient in new digital tools, but perhaps even more importantly, exposing them to a more "real world" collaborative design process.

---

[7] BIM Collaborative Studio student team: Hamed Aali, Nick Landiak, Neal Diehl, Steve Pfund, Alex Stough, Josh Winemiller

[8] The BIM Collaborative Studio was funded by a grant from the Raymond Bowers Program for Excellence in Design and Construction of the Built Environment

A small size interdisciplinary studio format was selected for the two initial offerings of this course (eighteen students from the Architecture, Landscape Architecture and Architectural Engineering departments). Tasks undertaken included: architectural, landscape and engineering design, energy analysis, cost estimating, scheduling, constructability, coordination and clash detection. Course content also included an overview of BIM and its application to the design and construction process (including organizational and application challenges and potential legal issues), current BIM software as well as BIM trends in the design professions and construction industry. The primary purpose of the second offering of this course was a design studio in which teams used BIM technology and collaborated to develop an integrated building design.

Building on the "lessons learned" from the 2009 BIM Collaborative Studio (100,000 GSF elementary school project), the project area program this year was smaller (20,000 GSF child care center) and we allowed the students to design the project from a "blank sheet of paper" rather than approach the project as a revision to a prototype design as we had done the prior year.

As the subject project was a real Penn State facility, we had the opportunity to involve the Director of Penn State Child Care as the "client" as well as the Project Architect and Structural and Mechanical Engineers of the actual project were available to the BIM Collaborative Studio teams for work sessions, feedback and project juries. This greatly enriched the course offering, motivated students and was reflected on the improved student course evaluations.

3. DEVELOPMENT OF AN ARCHITECTURAL ENGINERING IPD / BIM CAPSTONE PROJECT COURSE[9]

Traditionally the Architectural Engineering 5th year Capstone Project has been a two-semester individual project. Students select existing projects based on criteria specific to their option (structural, mechanical, lighting/electrical and construction engineering). In the fall semester the students become familiar with the project through detailed technical assignments. At the end of the fall semester the student develops a proposal to test specific proposed modifications to the building's design with the goal of improving building performance, cost and constructability.

In academic year 2009-2010 a team based interdisciplinary IPD / BIM approach was tested as an alternative capstone project. Three teams of four students (one from each of the AE options) were formed to study and propose alternative designs for The New York Times Building.

4. RECRUITMENT OF STUDENTS AND FORMATION OF PROJECT TEAMS

To test this new form of integrated BIM Collaborative studio we formed three student teams, each with a full complement of disciplines (Architecture, Landscape Architecture and the four AE options). Our goal was to not only find eighteen students, but eighteen highly motivated students with at least minimal background in REVIT and other BIM platform programs. To accomplish this, the course registration limit was set at eighteen and each student was admitted by instructor approval. Each student submitted their academic credentials along with a statement as to why they wanted to take the BIM Collaborative Studio. Additionally each student was interviewed prior to acceptance into the BIM Collaborative Studio course.

[9] The AE IPD / BIM Capstone Project was funded by The Thornton Thomasetti Foundation and The Leonhard Center for Enhancement of Engineering Education

Generally the recruitment process was successful although attracting qualified well motivated students (and exactly three of each discipline) takes considerable faculty time for outreach and organization the semester prior to the studio offering. The difficulty of scheduling classes across three departments, and the requirement that the architecture and landscape architects take the BIM Collaborative Studio as a second studio during the same semester impacted the ability to recruit students. Once the BIM Collaborative Studio students were identified an eighteen question survey was used again this year in an attempt to form teams that hopefully would have a greater than average chance of successful collaborative effort.

Two of the three BIM Collaborative Studio teams in Spring Semester 2010 worked extremely well together. There was strong collaboration in these groups and they seemed to enjoy working together. The third team was fairly dysfunctional throughout the semester. Their level of collaboration was much less and they tended to work as individuals even during the studio sessions. No clear leadership developed and communication was impaired. It is interesting to note that neither of the two more successful teams appointed a leader, but rather seemed to let leadership evolve based on the task at hand.

A similar approach was taken to identify students and form teams for the AE IPD / BIM Capstone Project. For the first test of this interdisciplinary approach all three teams performed at an acceptable level and the relative performance was much more consistent than what was seen with the BIM Collaborative Studio (many of the AE IPD / BIM Capstone students had participated in the BIM Collaborative Studio the prior year). That said each of the AE IPD / BIM Capstone team faced challenges to collaboration that were not dissimilar from those of the BIM Collaborative Studio.

5. FACULTY AND EXTERNAL RESOURCES

A coordinating instructor and a teaching assistant were assigned to teach and administer the BIM Collaborative Studio. Additionally faculty members from Architecture, Landscape Architecture and Architectural Engineering attended studio work sessions and formal project reviews. For the AE IPD / BIM Capstone project, in addition to the two Capstone Project coordinating instructors, a faculty member from each of the four AE disciplines was assigned to consult with the three AE IPD / BIM Capstone teams. Interdisciplinary efforts are by their very nature, labor intensive. While input by jury members at presentations is valuable, there is a need for on-going discipline support for the students in order to gain maximum benefit from the BIM and IPD.

By using a real Penn State facility project in the Spring Semester 2010 offering of the BIM Studio we were fortunate to have not only the Project Architect and Mechanical / Electrical Engineers, but also the Director of Penn State Child Care available to the project teams for work sessions, technical input and project juries. For the AE IPD / BIM Capstone Project representatives from the owner and the building design consulting team were also available to the student teams. A BIMWiki[10] previously developed at Penn State was also made available as a resource for students in both BIM Collaborative Studio and the AE IPD / BIM Capstone Project.

[10] http://www.engr.psu.edu/bim

Providing wide-ranging discipline support is a significant challenge for any interdisciplinary course offering. To successfully facilitate this type of course however, these resources must be available through internal and/or external resources.

6. STUDIO AND TEAM WORK SPACE REQUIREMENTS

It is not only a matter of appropriate hardware and software, but also one of appropriate studio layout to facilitate collaborative team work.

Face to face interaction (which in spite of digital advances is still critical to the integrated design process) remains somewhat of a challenge for the BIM Collaborative Studio however as none of the existing studio facilities are configured to effectively accommodate a multiple collaborative BIM team process. During studio time it would be ideal if each team could have access to sufficiently powerful computers loaded with all necessary software and be able to gather around a large digital screen to facilitate sharing of information and interaction (for three teams this would require three computers and three large format screens in one studio).

For the AE IPD / BIM Capstone Project more powerful computing hardware was available however we found that studio layout and the shape, size and number of conference tables also impacted the ability of the teams to effectively collaborate.

7. PROJECT SELECTION

For the initial 2009 offering of the BIM Collaborative Studio the faculty shared the concern that unless we found a way to "jump start" the architectural design process there was some risk the architect on the team might take a good portion of the semester developing the initial design concept. Significant delay in establishing an architectural direction would make it difficult for the other team members to interact with the design process early enough to develop a sufficiently complex interdisciplinary building information model and integrate the work of the various design disciplines. To solve this perceived problem for the 2009 BIM Studio we decided to use a "prototype" project design for an elementary school as a starting point.

In observing this initial BIM Collaborative Studio offering, as well as reviewing the student feedback that year, it was clear the prototype approach was a source of great frustration for the architecture students and also possibly reduced the sense of team "ownership" of the final product. Additionally it was clear the elementary school project was too large for a first time integrated BIM exercise.

For the 2010 offering of the BIM Collaborative Studio during, we selected a "real" project – the new Penn State Day Care Center which was not only of a more manageable size (20,000 vs. 100,000 GSF), but also allowed for invaluable contacts with the real project consultant and client team.

Although the student teams were given the same project brief and area program used for the actual Penn State Child Care Project, the plans and details of the actual project were not made available to the students until late in the semester when the student designs were well established.

We may have found the "perfect" project for the Spring Semester 2010 BIM Collaborative Studio in terms of scale, location, and close integration of architecture and landscape architecture. The availability of a real client, project team and detailed design information for the actual project greatly enriched the experience as well as provided technical disciplinary input that would not have been available from faculty due to other teaching / research / service activities.

For the AE IPD / BIM Capstone Project the New York Times Building was selected as the subject project. This landmark building proved to be an exciting, but also a very challenging project. While the students did have some access to the owner and the project design team, the building contractor (core and shell) was no longer operating in the United States thus limiting valuable construction information. As the New York Times Building was designed near the beginning of the "BIM revolution" existing BIM models for the project were limited in scope requiring the students to build the base design BIM model which was very time consuming. Additionally proposing changes that would impact appearance of this high profile building were potentially very controversial.

8. PROJECT DELIVERABLES

For both the BIM Collaborative Studio and the AE IPD / BIM Capstone Project semester schedules with deliverables were developed to guide the overall team efforts as well as the individual disciplines. During the fall semester the AE IPD / BIM Capstone Project teams responded to specific technical assignments (discipline and team based) as well as developed their own team proposals to guide the work in the second semester. During the second semester, the AE IPD / BIM Capstone teams used BIM as a collaborative platform to test and technically coordinate their proposals for improving the subject building performance.

As the majority of the other AE students were still undertaking individual capstone projects with very extensive discipline based requirements, there was a tendency for some faculty members consulting with the BIM teams to expect that the BIM students complete the full array of the option requirements expected of an individual capstone project student in addition to the collaborative work required by the IPD/BIM approach. For 2010-2011 more specifically defined deliverables along with an increased oversight by the coordinating instructors will be applied to try to avoid the potential for "deliverable overload". It is interesting to note that whenever work assignments are made by discipline (BIM Collaborative Studio or AE IPD / BIM Capstone Project) there is a tendency for students to fall into the "silo trap" rather than a "team first" focus. As the AE Capstone Project is the final major project for the AE students some potential BIM team students have expressed reservations of having their "fate" depend on the performance of others.

As a well-planned process is the key to integrated design, both the BIM Collaborative Studio and AE IPD / BIM Capstone Project teams proposed work flows using the BIM Execution Planning Guide.[11] These workflows were updated by the teams throughout the project duration.

---

[11] BIM Execution Planning Guide developed by CIC Research Group, Department of Architectural Engineering, The Pennsylvania State University in association with the buildingSmart alliance. Development of this guide was funded by: The Charles Pankow Foundation, The Construction Industry Institute, Penn State Office of Physical Plant and The Partnership for Achieving Construction Excellence. http://www.engr.psu.edu/ae/cic/bimex/

Illustration 2: Student Systems Integration Model, BIM Studio 2010[12]

The BIM Collaborative Studio had four major presentations during the semester culminating with the final presentation which focused on BIM modeling and technical integration as well as "lessons learned" regarding integrated design process and BIM information exchange. This final presentation was made to a jury consisting of the real project consulting and ownership team along with the University Architect and others with significant BIM project experience. Throughout the semester construction management students developed schedules, constructability reviews, value engineering analysis, site logistics plans and cost estimating input as well as monitored and updated the BIM Execution Plan. After the final presentation the real project contractor line item cost and schedule were reviewed in detail as compared to the student teams' estimates and schedules. As an additional means of budget control, the as-designed area program was calculated by the project teams at each stage of design and compared in detail to the real area program.

In addition to various technical assignments, the AE IPD / BIM Capstone Project teams were required to make a number of preliminary presentations as well as two final presentations, the second of which also included outside jury members.

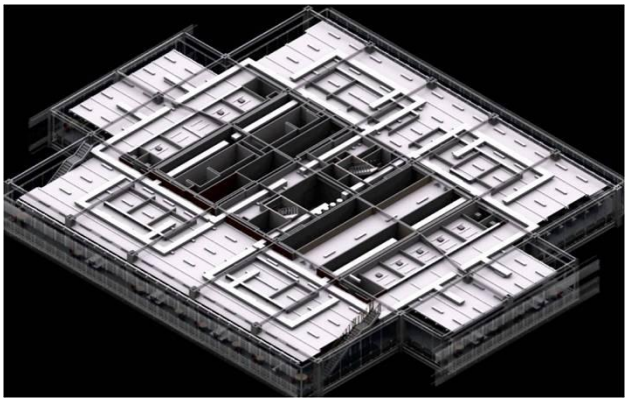

Illustration 3: Student Systems Integration / Construction Sequence Model, AE BIM Capstone Project, 2010[13]

[12] BIM Collaborative Studio student team: Hamed Aali, Nick Landiak, Neal Diehl, Steve Pfund, Alex Stough, Josh Winemiller

[13] AE IPD / BIM Capstone Project student team: Chris Wiacek, Brian Cox, Peter Clarke, Erika Bonfanti

Invited jury members provided actual project experience as well as IPD / BIM expertise and important "real world" commentary and feedback for both BIM Collaborative Studio and the AE IPD / BIM Capstone Project.

While we only have one year of history for the AE IPD / BIM Capstone Project it was interesting to note that the quality, quantity and complexity of student work for the BIM Collaborative Studio during Spring Semester 2010 were significantly improved over the 2009 BIM Collaborative Studio offering. In general, this improvement can be attributed to implementation of "lessons learned" from the prior year. In particular, changing the size, type and location of the project (including important real client and project team discipline input) as well as allowing the students to create original design work (vs. modification of a prototype design) were significant factors in improved student work.

9. STUDENT / TEAM PERFORMANCE AND COURSE FEEDBACK

Surveys were developed to gain individual, team and course feedback. For the BIM Collaborative Studio these surveys were conducted at mid semester and after the final presentation. For the AE IPD / BIM Capstone Project these surveys were conducted at the end of the two semester project.

9A. PEER AND TEAM PERFORMANCE SURVEYS

The Peer Survey asked thirteen questions related to the individual characteristics of members of high performing teams. Each student completed a peer survey for each of his/her teammates. Additionally each student also completed the same survey for themselves prior to receiving the results from their peers to allow them to compare their own perceptions of their individual performance vs. the perceptions of their teammates.

The Team Performance survey consisted of twenty three questions designed to measure five important factors found in high performing teams (Team Vision, Participative Safety, Support for Innovation, Task Orientation, Task Cohesion).

In the 2010 BIM Collaborative Studio two of the three teams worked very well together while the third team struggled with communication and collaboration. There was a correlation between the ability of the teams to effectively work together and the quality of the student work product. The Peer and Team Performance Surveys also confirmed these observations and were used as tools to provide specific feedback and suggestions for more effective communication and collaboration.

Table 1: BIM COLLABORATIVE STUDIO 2010 - SELECTED TEAM PERFORMANCE QUESTIONS

Likert Scale: 1 = Strongly Disagree, 5= Strongly Agree

	Team #1	Team #2	Team #3
Team Vision	4.7	4.0	4.8
Participative Safety	4.7	3.4	4.8
Support for Innovation	4.3	4.0	4.8
Task Orientation	4.1	3.5	4.5
Task Cohesion (united to reach goals)	4.5	3.7	5.0
Team Averages:	4.46	3.72	4.78

The differential of performance of the three AE IPD / BIM Capstone teams was much less than with the BIM Collaborative Studio teams. Accordingly the Peer and Team Performance surveys were more consistent. As the surveys were only conducted at the end of the two semester AE IPD / BIM Capstone Project there is no data available for this course related to the trending of individual and team performance over the life of the project. While the BIM Collaborative Studio teams were closely monitored (twice weekly two-hour studio sessions), the AE IPD / BIM Capstone teams were allowed to work much more independently. While the overall team performance was more consistent than in the BIM Collaborative Studio, the end of project AE IPD / BIM Capstone surveys indicated there were a least a couple of fairly dysfunctional team relationships that were not apparent to the faculty with more casual observation. Next year we intend to administer the Peer and Team Surveys twice each semester in order to obtain an early warning of team issues. Again this points to the need for significant faculty involvement in team based collaborative projects.

9B. IDP / BIM SURVEYS

Two more surveys were developed for both courses: A ten question survey to measure the student's response to the Integrated Project Design / Delivery Process and an eleven question survey to measure response to BIM technology.

Table 2: BIM COLLABORATIVE STUDIO 2010 - SELECTED STUDENT IPD FEEDBACK QUESTIONS

Likert Scale: 1 = Strongly Disagree, 5= Strongly Agree

	Team #1	Team #2	Team #3
"It was easier to design using IPD"	3.5	3.2	3.3
"Early understanding and agreement on workflows is critical to successful IPD"	3.5	4.5	4.5
"Understanding of "lead/lag" and interdependency is critical to successful IPD"	4.0	4.7	4.7
"Using IPD I gained a new understanding of other disciplines"	4.8	4.3	4.7
"Successfully implementing IPD should result in better coordination and fewer change orders"	4.8	4.7	4.7

While the IPD and BIM technology survey scores for the BIM Collaborative Studio were a bit more random than the other Team and Peer surveys, overall these surveys also reflected the

relative project performance of the three teams. Results from the AE IPD / BIM Capstone project teams were similar.

Findings of interest from the BIM Collaborative Studio IPD Survey:

- All teams, particularly in the early stages of the project, found IPD to be somewhat difficult and more time consuming (versus designing the project on their own or in a smaller group).
- "Lead / Lag" of information flow is critical
- All learned more about other disciplines in the design process
- All agreed that successful implementation of IPD should result in a better design

Table 3: BIM COLLABORATIVE STUDIO 2010 - SELECTED STUDENT BIM TECHNOLOGY FEEDBACK QUESTIONS

Likert Scale: 1 = Strongly Disagree, 5= Strongly Agree

	Team #1	Team #2	Team #3
"Creating and sharing a BIM was relatively easy"	3.4	3.5	3.7
"Sharing information from software to software was relatively easy"	2.8	3.7	3.8
"Our actual workflows turned out to be similar to our plan"	2.4	2.3	2.7
"BIM improved the coordination and quality of our design"	3.9	4.2	4.7
"3D visualization and clash detection allowed for a better understanding and coordination of our design"	4.3	4.5	4.7
"Using BIM enhanced our ability to produce a more sustainable design"	3.8	3.3	3.8
"Successfully implementing BIM should result in better coordination and fewer change orders"	4.7	4.7	4.8

Findings of interest from the BIM Collaborative Studio BIM Technology Survey:

- All teams found that the creation and sharing of a Building Information Model was somewhat challenging.
- Actual workflows turned out to be significantly different than the planned work flows (both of these responses likely due to relative lack of experience in collaborative BIM efforts).
- All agreed that 3D Clash Detection was a powerful design tool
- The connection between BIM and sustainable design was not as strong as anticipated (or should be) possibly due to workflow challenges encountered by the student teams.
- All felt that successful implementation of BIM would result in a better quality design

Similar findings were noted in the AE Capstone Project IPD /BIM surveys.

9C. STUDENT COURSE FEEDBACK SURVEY

A detailed survey of student feedback for the BIM Collaborative Studio was also conducted after completion of the final deliverables. This was the same course survey utilized for the BIM Collaborative Studio in Spring Semester 2009 allowing for comparative data on student feedback data for the two years of the BIM Collaborative Studio.

Table 4: BIM COLLABORATIVE STUDIO 2010 - SELECTED STUDENT COURSE FEEDBACK QUESTIONS

Likert Scale: 1 = Strongly Disagree, 5= Strongly Agree

	Team #1	Team #2	Team #3
"After the BIM Collaborative Studio I am more comfortable working on multi-disciplinary teams"	4.3	4.3	4.8
"After the BIM Collaborative Studio I know more about other discipline roles, how they interface with each other and how each can collectively contribute to the design process"	4.3	4.3	4.5
"The BIM Collaborative Studio helped me prepare for the "real world" of design and construction"	4.5	4.3	4.7
"The BIM Collaborative Studio was a more effective learning experience than my previous design studios"	4.3	3.5	4.3

Quantitative and verbatim student course feedback was significantly improved over the 2009 BIM Collaborative Studio. We believe the choice of the daycare project with smaller program and allowing the students to have greater control (ownership) over the project design were factors leading to the improved scores.

- In general, student evaluations of the 2010 BIM Collaborative Studio were very favorable. It was interesting to note that for the 2009 BIM Collaborative Studio, AE students tended to respond more favorably than either Architecture or Landscape Architecture students. In 2010 the evaluations and scores were much more consistent across all disciplines with much more positive responses from Architecture and Landscape Architecture students.
- AE students were somewhat frustrated by the "slow design progress". Architecture students were also sometimes frustrated by having so much input from others in the early design phases. The initial design process also took longer when there were so many people providing input.
- The interface of software for information exchange was generally challenging.
- Valuable lessons in team and interdisciplinary work were gained and the attempt to create a "more real world" design process was appreciated.
- All felt they learned more about other design disciplines' roles and after the BIM Collaborative Studio students felt much more comfortable working on multi-disciplinary teams.
- The "lead / lag" and work flow of the design process had to be carefully managed and good communication was essential. The role of each discipline has to be well defined while at the same time emphasizing the overarching goal of team collaboration. Students realized how dependent they were on each other to make progress.

- Most students felt that the BIM Collaborative Studio was a very effective studio learning experience.
- Most students felt the team and 360 degree peer surveys were helpful to understand teammate perceptions and improve team performance.

Student feedback on the AE IPD / BIM Capstone Project course was similar although as it was the first offering of the BIM Capstone Project no comparative data is available.

10. THE PATH FORWARD

Hands-on integrated BIM experiences are critical to prepare students for future leadership roles in the rapidly changing fields of design and construction. It is important to not only teach the new digital technology, but also to expose students to techniques which encourage successful collaboration and break down "discipline silos" as well as the compartmentalization of the design process.

For students to be successful in these intense BIM collaborative learning experiences the students need to enter into the integrated courses with reasonably well-developed BIM program skills, be provided with computers and studios to support digital and team collaboration as well as receive significant and on-going support from faculty and outside individuals who have a wide range of disciplinary knowledge and experience with the Integrated Design Process and Building Information Modeling. Additionally, ways must be found to overcome multi-discipline scheduling issues (students and faculty).

While we have encountered a number of challenges in offering integrated BIM courses, which have been discussed in this paper, we intend to intensify our efforts based on lessons learned to improve the BIM Collaborative Studio and the AE IPD / BIM Capstone Project courses to better prepare our students for their future careers.