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Student Perceptions of Flipping a Mechanical Engineering Design Course*

JACQULYN BAUGHMAN
Department of Mechanical Engineering, Iowa State University, 2529 Union Drive, Ames, IA 50011-2030, USA.
E-mail: jacqulyn@iastate.edu

LESYA HASSALL
Center for Excellence in Learning & Teaching, Iowa State University, 701 Morrill Road, Ames, IA 50011-2102, USA.
E-mail: lesya@iastate.edu

XIAOWEI XU
Department of Apparel, Events, and Hospitality Management, Iowa State University, 2302 Osborn Drive, Ames, IA 50011-1078, USA.
E-mail: xiaoweix@iastate.edu

A multi-section mechanical engineering sophomore design course was flipped to engage future engineers in interactive online learning modules and pre-assessments prior to hands-on collaborative lab sessions. A mixed methods approach was used to achieve our objectives to capture and understand student experiences with course online and in-lab components, and their impact on student self-reported comfort with flipped delivery. Responses from 158 students to a course exit survey demonstrated high comfort with the flipped delivery paired with positive online and in-lab experiences. The strongest positive predictors of comfort determined by factor analysis and block-wise regression were self-reported investment in learning as part of student self-regulation, and the effectiveness of course online learning modules. The strongest predictor of discontent with flipped delivery was associated with unanswered questions upon completion of online learning modules. Qualitative analysis of student responses to three open-needed responses supplemented quantitative results to demonstrate that although student own estimation of sufficient self-regulation for succeeding in the flipped classroom was very high, their self-regulatory behavior was complex, developing and not as efficient as readily presented in their responses to the Likert scale questions. Findings are discussed in connection with the flipped design/development, and implications and recommendations for engineering education.

Keywords: engineering design; flipped classroom; instructional methods; mechanical engineering; pedagogy; student experiences

1. Introduction

Much too frequently traditional engineering design classrooms focus on imparting theoretical knowledge on future engineers allowing for minimal uninterrupted face-to-face time for building a design product, collaborative reflection, and evaluation of the design and production stage [1]. Intensive hands-on collaborative classroom sessions are integral to teaching engineering design [2]. A mechanism for learning and in itself a learning process, engineering design is neither an entirely solo nor a totally formal affair. Engineers are expected to work in teams and be cognizant of different viewpoints and ways to accomplish a task at hand. Informal negotiations, discussions and banter among members of a design team looking for a solution to an engineering problem are part of active learning engagement [3] that occurs largely during face-to-face (FTF) interactions.

The fundamental idea behind flipping a classroom is that face-to-face class sessions become spaces for active engagement, where students practice and problem-solve together and under the guidance of the instructor, who provides immediate and meaningful feedback and assistance. The out of class component of a flipped classroom is meant to prepare students for active hands-on learning in class. Students engage with scripted instructional materials in a systematic way followed by frequent self-assessments and additional materials for those in need of additional intervention. In contrast to direct instruction outside of the classroom, the face-to-face component of a flipped classroom can encompass a spectrum of learning approaches, including cooperative learning [4], collaborative learning [5] and problem-based learning [6]. In-class problem solving is aided by student exposure to new content prior to the face-to-face component of the course. Thus, the more students learn on their own prior to class, the more productive they are in class. A flipped classroom can provide valuable face-to-face time for productive team learning activities, discussion of difficult concepts and problem solving by replacing instructor-dominated lectures with out-of-class computer-based individual instruction, such as online interactive video and text-based content [7].

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Literature reports on the flipped classrooms are somewhat mixed, but generally positive [8]. Studies show that video lectures (only slightly) outperform in-person lectures [9]. Instead, flipping the emphasis towards student preparation and independent engagement with lecture materials, such as listening to or watching a video explanation, reading book chapters and self-assessing current understanding via a follow-up assessment makes for more productive educational activities in-class [10]. Flipped classrooms are credited with many learning benefits [11], such as more rigorous student pre-class preparation, in which independent content mastery is tied to student ability to self-manage, self-assess and recognize connections between previous and new knowledge; respecting a student's own pace of learning; effective and creative in-class time with increased student engagement for solving real-world problems [12]. Engineering graduates need to be able to solve real-world problems and work in teams, which suggests the merit of flipping a classroom, however, limited research currently exists on the impact in engineering education [13]. In higher education making room for active reflection and experimentation, rather than passive knowledge consumption and listening is key for creating strategic, goal-motivated and resourceful learners [12]. A primary advantage of the flipped approach is that it offloads passive lecture content to outside the classroom, freeing up time inside the classroom for a more active and higher order learning environment [14], and increasing self-confidence in a supportive and collaborative classroom environment. Despite the growing number of flipped courses, however, quantitative information on their effectiveness remains sparse [15].

Although flipped classrooms can have many advantages, some issues, such as student resistance and instructor time required to integrate out-of-class and in-class elements, have been identified; thus leading some instructors to question the value of changing to a flipped classroom. Two significant student problems with flipped were reported in a recent STEM teacher poll [16]: (1) students may initially resist doing pre-class work independently and consequently may be unprepared for participating in active learning during class, and (2) pre-class content if not crafted carefully and not targeting the zone of proximal development [17] might be perceived as not challenging and thus not promoting learner engagement. Both are indicative of the departure from viewing students as passive consumers of knowledge and the shift towards encouraging learner motivation and engagement as well as respecting diverse ways in which students learn, engage and express what they know. The manner in which instructors choose to implement a flipped classroom is unique to their teaching style. The main challenge for the instructor involves the extra work of creating the lecture videos the first time a course is taught in the flipped approach [14]. Thus, no two classes, whether employing lecture or flipped learning pedagogies, are identical [18].

1.1 Online and self-regulated learning

Self-regulated learning (SRL) strategies can be an integral part of the student learning process in an engineering design course. Winne [19] posits that SRL is inherent in learners; in academically poor students it might be less complex, yet strategic use can be fostered by environmental influences. SRL skills include goal setting, time management, task strategies, and environment structuring [20], and a potential learning process that enhances students' motivation to learn and reflect on their learning process, and thus contributes to the resolution of their learning [21, 22]. The SRL model assumes that students are able to monitor and regulate the various aspects of their cognition, behavior, and study environments, and can effectively assess whether or not their learning process is working for them, or if changes need to be made [23]. Success in a flipped class requires student preparation for class by performing a task (e.g. watching a lecture) that is traditionally considered a passive event. They need to be aware of their interaction level with the task and regulate their motivation. Optimal preparation may occur through the utilization of SRL strategies [24]. Wolters, Pintrich, and Karabenick [25, p. 254] captured the potential relationship between SRL and the flipped model:

> "The challenge to complete academic work at home without the structure of social pressures to continue working that are present in the classroom can be even more difficult. In light of these obstacles, students' ability to actively influence their own motivation is viewed as an important aspect of their self-regulated learning."

In a comparison study, Lee and Tsai [26] found students were more interested in utilizing SRL strategies in online learning than traditional learning contexts. Additionally, Liaw [27] found that learners' attitudes can directly influence cognition, which in turn has a direct effect on behaviors. In a follow-up study, looking specifically at how student perceived satisfaction of online learning environments (i.e., acceptance of system and degree of comfort using system) affected SRL, results indicated that SRL in online environments was predicted by perceived satisfaction; explicitly, student attitudes about online environments affected learning behaviors [28]. As a result of technological advancements, self-regulated learning strategies are no longer restricted to interactions between individuals' psychological views and their learning, as these interactions have been extended to include use of some technological tools [29, 30].

1.2 Problem statement

The purpose of this study is to expand knowledge about flipped classrooms in engineering education by gleaning insights into student experiences in a flipped multi-section undergraduate introductory sophomore engineering design course. Prior research on the student perceptions of flipped classroom either employs qualitative method by analyzing students' responses to open-ended survey questions [31] or quantitative method by comparing pre- and post-course survey responses [13], this study is different in that it analyzes both quantitative and qualitative data to understand student perceptions of the relationship between the out-of-class and in-class components of the flipped classroom. Additionally, this study empirically investigated how such perceptions might have been impacted by student self-regulation. Specifically, our research interests revolved around the following:

1. What were student perceptions of the online and in-lab experiences of the course?
2. How did student experiences with the online component, more specifically online interactive modules and pre-assessments, and the in-lab component in which team-based active learning occurred impact their self-reported comfort with the flipped delivery?

2. Rationale for flipping

The Mechanical Engineering 270 (ME 270) "flipped" decision was motivated by several pedagogical concerns. These included course enrollment increases, space availability conflicts, and variable instructional quality/content, accessibility, and student engagement issues. As a large enrollment course, ME 270, approaching 300 students, required sufficient physical space for a large lecture once a week. With overall university enrollment at its highest in history, it became increasingly challenging to compete with the needs of other large lecture-based courses, and coordinate lecture hall capacity. However, elimination of a large lecture needed to be paired with alternative student access to ME 270 course content. In their end-of the semester course evaluations, exit interviews and random discussions, our students were clear: it was not the content they objected to, it was the lengthy, non-interactive and inflexible lectures that took a toll on student motivation and engagement. In addition to the student responses, each instructor also documented what they learned from their own sections. Our informal analysis of the student feedback data and regular discussions within the teaching team helped to identify three key areas to improve the course with the flipped implementation:

1. Course content and instructional consistency to effectively use in-class time. Instructors previously spent extensive time on lecturing in their sections, covering material more in-depth, or most often reiterating what was already discussed in the large lecture; content instructor monologues varied from section to section.
2. Flexible and accessible just-in-time and on-demand content: students complained about boring lectures and asked for flexible online engagement with new content to free time for actual design work. Additionally, they asked for the possibility of working with content material on their own terms and pace.
3. Focus group interviews with exiting students indicated that lectures were perceived as uninspiring, repetitive and non-participatory. They needed to be replaced with digestible interactive multi-media content tied to the skills to be practiced in the labs.

2.1 Pre-flipped course description and logistics

Mechanical Engineering 270 (ME 270), is part of mechanical engineering's critical design course chain, and are "chained" together by prerequisites. It serves as the foundational application of engineering design tools and methodologies, shared across the chain. A course description and learning outcomes are shown in Table 1. As a discipline PBL course, student design teams create micro-economy kits (projects) resulting in a functional prototype design that promotes sustainability and economic growth in under-developed/developing nations, and should:

1. Meet a basic need in a developing region.
2. Improve or create a self-sustaining economic activity.
3. Be made from a low-cost kit, using as much "local content" as possible.
4. Be sold and serviced by local entrepreneurs.

During the course, student design teams follow the Design for Six Sigma (DFSS) methodology by working through a real-life design simulation utilizing a toolbox called DMADVR (Define-Measure-Analyze-Design-Verify-Report) in a phase-gate exit review process shown in Table 2. The DFSS methodology allows novice engineers to experience the industry's processes for designing products that

Table 1. Course Title, Description and Learning Outcomes

ME 270 Course Description	Course Learning Outcomes
Introduction to engineering design and overview of mechanical engineering design applications to thermal and mechanical systems. Introduction to current design practices used in industry. Semester-long team project focused on addressing societal needs. Past projects include designing human powered charging systems and products for developing nations.	1. Demonstrate effective team work skills. 2. Create technical reports that possess appropriate structure, grammar and tone. 3. Identify the ways in which social, economic and environmental issues (the three legs of the sustainability table) impact or are impacted by the activities of the designer.

Table 2. The DMADVR Toolbox Six Phase-Gates: Key Phase-Gate Exit Questions

Define	What are the customer demands and how do they define your design and product goals?
Measure	What are the characteristics critical to your design?
Analyze	How can you optimize your design and product development based on the data collected during the Define and Measure Stages?
Design	How do you create a product and/or process that will be an improvement from status quo?
Verify	Does the product do what it is expected to do? What does it take to implement the improved product and/or process?
Report	What documentation of the design and development do you have in place?

meet customer expectations [32] and yield a higher level of performance [33].

ME 270 typically has 6 sections of 42 students (252 total), with a TA assigned to each section. Prior to flipping, the course had a 50 minute, all-student lecture once a week, and 6 hours of F2F team design work in a lab space. DFSS tools were previously introduced in the large group lecture by faculty, industry speakers, and teaching assistants. Individual instructors also covered supplemental material beyond the scope of the group lecture during the F2F time. These lectures occupied 30 minutes to one hour of the total F2F time (two-hour duration).

2.2 Flipped course logistics

A direct result of flipping the course was the elimination of a 50-minute lecture. Instead, interactive online modules and assessments were created to expose students to new content prior to FTF lab sessions. The online learning modules were developed through a collaboration between Mechanical Engineering and the Center for Excellence in Teaching and Learning at Iowa State University. During F2F lab sessions, each section instructor spends time briefly summarizing major points of the learning modules, answering student questions, initiating student discussions, conducting team-building activities and, more importantly, accommodating team-based design projects.

Nine learning modules were developed using Softchalk, a content authoring software tool, and integrated into a course master template residing in the institutional learning management system Blackboard (see Fig. 1).

The learning modules contained course content videos and text materials, as well as. industry's perspective vidoes on DFSS tool usage captured on site with a local industrial partner (each a

Fig. 1. A screen shot demonstrating a range of activities in online learning module.

maximum of 15 minutes in length). Text and videos were accompanied with interactive exercises, such as drag and drop, matching, sorting and quizzing. The students were allowed to work through the learning modules at their own pace and complete a graded assessment (quiz) prior to F2F sessions. All online materials including the Blackboard course were accessible 24/7. In class, the students were expected to ask questions and participate in class discussions while working on the team prototypes and applying the appropriate DFSS tools introduced in the learning modules. This course flow had a significant impact on the student role in the class.

3. Methods and results

3.1 Quantitative analysis

Upon completion of the course, the students were asked to participate in a post-assessment survey, which probed into their perceived flipped classroom comfort levels by examining two major components: (1) pre-class interactive online learning modules, and (2) self-reported student self-regulatory mechanisms. The surveys were conducted across all six sections of ME 270 (252 students). The measurement items in the post-assessment survey were adapted from an existing exit survey [34]. Survey questions were modified to reflect the specifics of the flipped course design, and capture students' perceptions of the online learning modules' effectiveness, as well as, their self-regulatory behaviors. A total of 19 items were included in the survey. All items were measured on a five-point Likert type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Additionally, the survey included two open-ended questions probing into what worked well and what could be improved with the flipped course. The survey was administered via the Blackboard, which is an online course management system. Exploratory factor analysis and block-wise regression were two primary analytic tools.

3.1.1 Descriptive statistics and factor analysis

A total of 158 students' responses were collected, resulting in a response rate with a range from 54% to 63% across the six sections. The mean and standard deviation for each measurement item were shown in Table 3.

Exploratory factor analysis using SPSS 24.0 was conducted to cluster the remaining 18 items into meaningful factors to aid in analysis. For an item to be included in a factor, it needed to have a loading value above 0.4 [35]. For a factor to be retained, it needed to have at least four items [36]. The rotated factor matrix, resulting from a Maximum Likelihood (ML) extraction with oblique (Direct Oblimin) rotation method using the 1.0 eigenvalue cut-

Table 3. Descriptive Statistics and Factor Loadings of Survey Items (n = 158)

	Factor Loading	M	*S.D.*
Dependent Variable			
I was comfortable with this course's flow when I learned new content prior to labs and practices my skills in labs		4.00	0.81
Independent Variables			
Effectiveness of learning module (α = 0.83)		3.53	0.66
In labs, I frequently referenced what I learned in my online learning modules prior to labs	0.77	3.44	0.97
My online learning modules kept me interested and willing to learn new content on my own prior to labs	0.71	3.44	1.06
Videos in my online learning modules illustrated new content well	0.68	3.61	0.96
My online learning modules were relevant for what I did in labs	0.67	3.85	0.80
I enjoyed interactive exercises in my online learning modules	0.59	3.58	1.01
In labs, my questions about my online learning modules were answered to the satisfaction	0.59	3.77	0.78
I frequently re-visited my online learning modules after labs	0.56	2.80	1.17
I felt the course modelled well how engineering design worked in industry	0.50	3.80	0.92
Students' self-regulation in the course (α = 0.70)		4.09	0.53
My study habits worked well for this course	0.86	4.13	0.65
I felt invested in my learning in this course	0.56	4.00	0.78
I felt responsible for my team's success in this course	0.51	4.28	0.67
I feel I was productive during lab times working with my team	0.45	4.24	0.74
I was managing my time well in this course	0.44	4.23	0.56
Items not within a factor			
I took sufficient time to complete my learning modules prior to labs		3.74	0.85
My team members always reviewed online learning modules prior to labs		3.44	1.02
I seldom worried about failing a quiz after completing my online learning modules—the quiz was part of my learning prior to labs		3.65	1.11
I found adequate assistance from my instructors and TAs after labs		4.01	0.79
I had many questions after completing my online learning modules prior to labs		2.78	0.93

Note. M = Mean; S.D. = standard deviation; α = Cronbach's alpha.

Table 4. Results of Regression Analysis for Model 3

Variable	β	**S.E.**	**t**
Effectiveness of learning module	0.46***	0.08	7.04
Students' self-regulation in the course	0.22**	0.10	3.39
Questions after completing online learning modules prior to labs	–0.17*	0.05	–2.87
Assistance from instructors and TAs after labs	0.17*	0.06	2.80
R^2		49.6%	

Note. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

off criterion indicated two main factors emerged. Of the 18 items, eight items related to students' experiences with the learning modules and in the labs, were consolidated into a single factor assessing the effectiveness of learning modules, while five items loaded into a single factor assessing students' self-regulation in the course. The remaining seven items did not load onto a factor and were retained as individual item predictors. The Cronbach's alpha values for two extracted factors were 0.83 and 0.70, respectively, which surpassed the commonly adopted threshold value of 0.70 [37]. See Table 3 for a complete list of measurement items and their factor loadings. Additionally, deductive qualitative analysis was performed on the student responses to two-open ended questions. All responses were coded and grouped into large themes to look for similarities and differences.

3.1.2 *Block-wise regression analysis*

Block-wise regression was utilized to examine the factors influencing students' comfort with the flipped course flow. The average scores for effectiveness of online module and students' self-regulation in the course were obtained. Variables were entered as blocks to parse the influence of variables and understand how that affected the variance explained by each model. In the first model (Model 1), we included effectiveness of learning module and self-regulation variable. In the second model (Model 2), additional five individual predictor items were entered into the model. A third, parsimonious model (Model 3) included only significant variables from the first two models.

Model 1, which focused on effectiveness of learning module and students' self-regulation, predicted 38.2% of the variance in students' self-reported comfort with the course flow. Model 2 accounted for an additional 5.7% of variance. Model 3, which accounted for 49.6% of the variance in students' self-reported comfort with the course flow, included four items: effectiveness of online learning modules ($\beta = 0.46$, $p = 0.000$), students' self-regulation in the course ($\beta = 0.22$, $p = 0.002$), whether students had many questions after completing their online learning modules prior to labs ($\beta = –0.17$, $p = 0.005$), and helpfulness of instructors and teaching assistants after labs ($\beta = 0.17$, $p = 0.006$). As shown in Table 4, the strongest positive predictor of a students' comfort with the course flow was the effectiveness of learning modules.

3.2 *Qualitative analysis*

The students were asked to respond to two open-ended questions probing into their achievements and challenges in the flipped course and one open-

Table 5. Advantages and Disadvantages of Online Learning Modules in the Flipped Course

Advantages of online learning modules	n
Watching video at length	101
Maximize hands-on engagement in class	95
Pacing learning	92
Practicing online before practicing on real life	77
Embedded exercises	71
Minimized lecturing	69
Engaging with content at length	61
Learning ahead	56
Self-evaluating	53
Engaging with online learning modules with teammates	51
Reviewing content any time	43
Jotting down questions to ask during class time	36
Asking peers for assistance	25
Disadvantages of online learning modules	
Incomplete information in online modules	113
Lack of straightforward connection between out-of-class and in-class activities	84
Student lack of ability to "connect all the dots" on their own	68
Lack of cohesion between online and classroom-instructions	41
Lack of immediate feedback when engaging outside of classroom	31

ended questions that allowed to share anything relevant in regard to the student flipped experiences. All responses were coded, counted and grouped into larger themes. An example below is a data snippet demonstrating the advantages and disadvantages of online modules in the flipped course (see Table 5).

The students generally agreed that they were comfortable with the flipped course flow and the way in which it respected their different ways of engaging and learning. This coincides with what was captured by the quantitative results. An elimination of the weekly 50-minute course lecture time was well received, as well as, making room for meaningful in-class discussions and uninterrupted team time for designing, building, and testing a functional prototype.

3.2.1 Benefits and challenges of the online learning modules

The online learning modules were reported to have solid content and accommodate flexible access which helped students to be in control of their time and engagement. The following benefits of the learning modules were frequently referenced:

1. Learning content ahead of the course schedule;
2. Reviewing learned content for missed insights;
3. Enjoying the convenience of pacing their learning;
4. Engaging with embedded exercises to better remember new content;
5. Watching videos that packed compressed hours of lecture time into digestible contextualized segments of information;
6. Self-evaluating without being punished for making a mistake.

Alongside the positive aspects, a number of students reported a certain disconnection between the content of the learning modules and the corresponding in-class session. The reported dissonance ranged from light differences between certain processes as they were represented in the learning modules and in-class sessions to the course's larger logistical issues when the modules referenced one way of completing an assignment while the students received explicitly different directions in class. As a result, students relied on instructor and TA guidance, as well as, the aid of their team members for accomplishing tasks rather than guidance provided in the learning modules. This became even more evident towards the end of the semester, when teams neared the completion of functional prototype design projects and dealt with unique engineering design problems, self-regulation issues, complex team dynamics and pressing deadlines. This finding might help to explain why the students reported having few questions after completing the learning modules in their responses to the Likert scale item: as the course dynamics became increasingly complex toward the end of the semester, the teams found themselves in different design and production stages.

The unique context of each section of the course demanded that student immediate learning needs and challenges be addressed even if at the expense of relevance between the content of the learning modules and the in-class sessions. This means that although the students expected a straightforward connection between what they learned online and what followed in the class, the actual connection between the two components of the course flow was more complex. Although the students were expected to come prepared to practice what they learned, the learning modules were not designed to cover the concepts fully; instead it was expected that in-class the students would articulate the gaps in their knowledge drawing on the learning modules. This was very different from student previous learning experiences—instead of spitting back digested information, they were asked to connect the dots on their own and then reflect and articulate on how the new content fit or did not fit with their previous knowledge. To vocalize that they in fact had questions after completing the learning modules might have put the students in an uncomfortable position. Likewise, the cookie-cutter assignment instructions were not part of the learning modules, because the intention was to challenge students and evoke their creativity, rather than dispatch the exact requirements for an excellence performance. So, bringing some uncertainty and messiness to learning was by design; the flipped format was a process to ensure that, in the end, student struggles are simply a part of learning.

3.2.2 Productive learning in class

The students agreed that online modules, integrated self-evaluation exercises and a follow-up graded quiz prior to in-class time helped to plan for and anticipate in-class sessions before they occurred. The in-class sessions were described as opportunities to put into practice what had been first brought to their attention in the modules, reinforce learned content through discussions with team members and the instructor and TA's guidance, and maximize time spent on collective engagement with design and production. A large number of student comments revolved around a feeling of accomplishment with which the students left the productive in-class sessions filled almost entirely with collaborative reflections, as well as, actual design and production of prototypes. The students were very vocal about appreciating minimal lecturing and maximum hands-on activities and uninterrupted design and production as unforeseen events, increased course workload, time constrains, team dynamics and other "noise" interfered with the scheduled timing for the prototyping as the semester progressed.

3.2.3 Self-regulation in the flipped classroom

Despite the high rankings that the Likert scale self-regulation items received, the responses to open-ended questions portrayed student self-regulatory behaviors as complex and developing throughout the course. The following self-regulatory behaviors were reported:

1. Scanning learning modules for the big picture before focusing on more complex parts;
2. Attempting self-assessments before watching videos for answers;
3. Jotting down notes while working with the learning modules;
4. Predicting the content in videos based on the surrounding text;
5. Asking many questions of the instructor and TAs;
6. Asking many questions of the members of a team.

Commonly describing themselves as responsible, purposeful and self-directed learners who employed different learning strategies for staying on top of their course work, the students tended to see their peers as somewhat less motivated and lacking self-management skills. However, many students noted that their experiences of collaborative work tended to change their perceptions of peers for the better.

Team work brought about unique challenges, such as adjusting to each individual's schedules, becoming cognizant of the strengths of team members, establishing effective team chemistry, discovering effective labor delegation practices, reconciling different communication and work styles, coining the rules for team ethics and accountability and accepting the team member's shortcomings. Several students reported that functioning as part of a team was a learning experience on its own, prompting them to reflect on their contribution to the prototype design, and comparing this to other team members. Attempting to solve team-conflict and self-regulate, students embraced soft skills: for some sharing equal amount of work was effective; for others, establishing individual member roles and accountability was critical. Having learned to trust, the students tended to more frequently discuss and review the content of the learning modules with their team members. Having struggled with the projects as part of a team, made many students realize they had become better learners capable of performing and overcoming difficulties. Having become cognizant of the strengths and contributions of the others, the students were more accepting of the individual differences.

4. Discussion

The quantitative analysis provides evidence that the flipped learning approach in engineering courses is well accepted by students. The majority of post-assessment survey item ratings exceeded a neutral assessment of three. Among 19 items, "I felt responsible for my team's success in this course" (M = 4.28) and "I feel I was productive during lab times working with my team" (M = 4.24) were two highest rated items, indicating the flipped approach allows for adequate team interactions. This aligns with Krafthwohl [38] regarding preparation for in-class collaboration, and Mok's [39] observation that in the flipped classroom students are more inclined to come to class prepared so as to be more confident in solving the problems during team work. Additionally, the block-wise regression suggests students who are highly-regulated were better adapted to flipped environment, which is consistent with a prior study indicating students who demonstrated high level of self-regulated learning were expected to opt for non-traditional learning environments because they offered the flexibility and convenience of learning at the students' own pace [40, 41]. Also, results highlight the importance of interactive online modules in students' perceptions of course flow, indicating positive student attitudes towards pre-lecture videos, which aligns with the findings of Long, Logan, and Waugh [42]. However, two items "I frequently re-visited my online learning modules after labs" (M = 2.80) and "I had many questions after completing my online learning modules prior to labs" (M = 2.78) received relatively lower ratings, indicating class topics might be easy to grasp immediately during the class [43]. As suggested by Mok [39], instructors could prepare additional videos to cater to top-tier students who want to learn advanced topics beyond the syllabus. Furthermore, students' perceptions of course flow are largely influenced by the number of questions they have after completing online learning modules. This suggests instructors make efforts to explain how asking questions facilitates meaningful knowledge construction in the flipped classroom. They can teach students to generate questions after completing an online module so that students could engage in productive discussion with their teammates on the team projects [44].

The qualitative analysis provided further evidence that students were comfortable with the course's flipped flow. This aligns with findings that student perceptions of a flipped classroom increase with familiarity, and students become more comfortable [45]. As the course developed and the students found themselves emerged in learning, team interactions, design, production and the pressing dynamics of the course deadlines, the flipped format accommodated diverse student needs and created room for resolving learning and logistical issues. The flipped format became a way to pro-actively react to what was occurring immediately in the classroom and intended by design—to help students learn that engineering design can be messy and fuzzy and that clear cut instructions do not necessarily lead to successful design products. The flipped classroom was structured to equip students with both, the discipline's conceptual knowledge, tools and processes, as well as, challenge and develop subject matter interest. Additionally, the students were learning to learn, becoming more cognizant of and developing their own self-regulatory mechanisms in order to stay on top of their course- and team work.

5. Conclusion

This study explored students' perceptions of a flipped engineering classroom utilizing qualitative and quantitative research methods. Student experiences in this sophomore mechanical engineering design course were positive. Students were comfortable with the flipped flow of the course, in which they engaged with interactive online modules and follow-up assessments prior to class, and practiced and reflected on new skills in class. As the course developed, students found themselves emerged in learning, team interactions, design, production and the pressing dynamics of the course deadlines, and the flipped format accommodated student diverse needs and created room for resolving learning and logistical issues. This flipped format became a way to pro-actively react to what was occurring immediately in the classroom and intended by design—to help students learn that mechanical design can be messy and fuzzy and that clear cut instructions do not necessarily lead to successful design products. The flipped classroom was structured to equip the students with both, the discipline's conceptual knowledge, tools and processes as well as challenge and develop their subject matter interest. Additionally, the students were learning to learn, becoming more cognizant of and developing their own self-regulatory mechanisms in order to stay on top of their course—and team work.

6. Limitations and future studies

There were three major limitations associated with this study. First, participants were restricted to the 158 students in a mechanical engineering undergraduate design course. The small sample size may limit the ability to generalize the findings. Second, interpretation and generalization of the findings to other geographic regions should be taken with caution because the data were collected using convenience sampling of college students enrolled in a large, multi-section course in a US-based Midwestern university. Third, data were collected from a multi-section course, and although common flipped content was utilized, inevitable variations in each section may have influenced student outcomes. The direction for future studies could include:

1. Exploration of flipped classroom feasibility in large-size classes (N > 50).
2. Examination of team satisfaction and peer assessment relationships.
3. Exploration of team conflict, team satisfaction, and peer assessment relationships.
4. Utilization of an additional entrance survey on the first day of class to observe meaningful differences in pre- and post-test scores

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Jacqulyn Baughman is a Senior Lecturer in Mechanical Engineering Department at Iowa State University. She has 18+ years of experience working in diverse industries holding leadership, as well as, consulting positions. She has been teaching engineering and business related courses for 15+ years, and continues to teach in her areas of interest and expertise: Manufacturing and Design Engineering, Product Development, Lean Product and Process Development Engineering, Six Sigma, Strategic Leadership, Marketing, Supply Chain Management, Management, Organizational Behavior, Statistics, Quality, and Project Management. Her publications and research interests include: Student Professional Development, Flipped Classroom, Dynamics of Teamwork, and Multidisciplinary Teams. In 2015, she led the successful Presidential Initiative Flipped Classroom Initiative implementation in a mechanical engineering design course.

Lesya Hassall leads technical and pedagogical support of audience response technology at Iowa State University. Her primary duties at the Center for Excellence in Learning and Teaching revolve around the design, development and implementation of faculty training opportunities for meaningful and effective applications of instructional technologies, including audience response technology. She is interested in the concept of sustainable online course design and development and collaborates on faculty-led projects that advance teaching and learning via instructional technologies. She earned her doctoral degree in Curriculum and Instructional Technology from Iowa State University's College of Education in 2007.

Xiaowei Xu is a Ph.D. candidate in the Department of Apparel, Events, and Hospitality Management at Iowa State University. Her main research area is within consumer behavior and information technology. Her methodological interests lie in the applications of structural equation models in the social and behavioral sciences.