ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15239

A Two-Dimensional Typology for Characterizing Student Peer and Instructor Feedback in Capstone Design Project Courses

Dr. Ada Hurst, University of Waterloo

Ada Hurst is a Lecturer in the Department of Management Sciences at the University of Waterloo. She has taught and coordinated the capstone design project course for the Management Engineering program since 2011. She also teaches courses in organizational behavior, theory, and technology. She received a Bachelor of Applied Science in Electrical Engineering, followed by Master of Applied Science and Doctor of Philosophy degrees in Management Sciences, all from the University of Waterloo. Ada's research and teaching interests include decision making under uncertainty, subjective probability, gender issues in STEM disciplines, design teaching, experiential and online learning, team processes, and expert vs. novice review in engineering design.

Prof. Oscar G. Nespoli, University of Waterloo

Oscar Nespoli is a Continuing Lecturer in Engineering and Mechanical Design in the Department of Mechanical and Mechatronics Engineering at the University of Waterloo (Waterloo). Oscar joined Waterloo following a 23-year career in research, engineering and management practice in industry and government. His teaching and research interests are in the areas of engineering design methodologies, design practice, engineering education and high performance, lightweight, composite materials design. Oscar is passionate about teaching engineering and, as part of his current role, maintains strong industry-university relations and a commitment to remain close to engineering design and management practice.

Before joining Waterloo, Oscar held the position of Sr. Program Manager at L-3 Communications Wescam (L-3 Wescam), a manufacturer of airborne surveillance systems for public safety, security and defense markets. Oscar had been employed at L-3 Wescam for 11 years, where he led multi-disciplinary teams toward the successful development and commercialization of several products to various markets. He was responsible for L-3 Wescam's largest defense programs.

Oscar worked at the Canadian Forces Department of National Defense failure analysis lab, where he was the Canadian Project Officer for an international program on F/A-18 bonded repair, and prior to that, a Research Engineer at the Canadian Space Agency. Oscar designed and qualified space flight hardware for a space experiment for Space Shuttle Flight STS-52 in 1993.

Earlier in his career Oscar led the design and development of products employing composite materials at Owens Corning Canada and contributed to the development of novel production machinery for the footwear industry with Bata Engineering.

Oscar earned a Master of Applied Science degree in Mechanical Engineering specializing in lightweight composite material structures from the University of Waterloo, and a Bachelor of Science degree in Mechanical Engineering from Queen's University (Kingston, Ontario, Canada). He became a licensed professional engineer in 1986.

A two-dimensional typology for characterizing student peer and instructor feedback in capstone design project courses

Abstract

This work in progress describes a study that is being conducted in a management engineering capstone design series of courses at a large Canadian university. The courses utilize a design review format that leverages feedback from both the course instructor (design expert) and student peers (design novices) in an informal face-to-face format. Prior research studying the efficacy of peer and expert feedback has found that expert comments and suggestions are often not well-understood or utilized by novices. Thus, in some domains, students have been shown to benefit more from feedback from multiple peers than a single expert. While the importance of peer review in the engineering and architecture disciplines has been established, there is little prior research on the quantity, content, type, and impact of feedback provided by novices, as compared to experts, in the context of engineering design.

The objective of this qualitative research study is to formally characterize, compare and contrast expert and novice feedback in engineering design review meetings. Preliminary observations have suggested that the addition of novice questions and feedback to the design review meetings enhances the quality and quantity of formative assessments. This study uses more robust data collection methods and analysis to refine and validate our initial findings. We video recorded and are in the process of transcribing 28 hours of review meetings of 14 capstone design teams that occurred in 2015. A minority of the meetings utilized instructor-review only, whereas the rest incorporated both student and instructor review. Using a grounded theory framework, the video transcripts will be coded and analyzed to better understand the differences in feedback provided by experts and novices. A literature review on the potential differences that may arise due to experience in the design process leads us to propose a new two dimensional typology of feedback that captures both its content - the design stage/activity being addressed – as well as the form the feedback takes. A portion of the already-transcribed review meetings are used to illustrate feedback comments of various permutations of content and form arising from instructor and student reviewers. In future work, the chosen typology will be utilized, and likely further refined, to analyze the complete transcribed data. The overall study aims to contribute to our understanding of the effectiveness of face-to-face peer-review in engineering design education.

1. Introduction

Pedagogical research has long been concerned with the issue of how feedback can best promote student learning. In a review, Shute[1] defines *formative* feedback as "*information communicated to the learner that is intended to modify his or her thinking or behaviour for the purpose of improving learning*"(p.154). In the context of engineering design education and capstone design courses in particular, formative feedback is regularly provided to students in design review meetings. These are held at various points in the project progression, often coinciding with the completion of major design milestones, and are attended by students, the course instructor, the project client, and other stakeholders.

Traditionally design reviews have been attended by only the students directly involved in the design. Yet, the broader education literature has long advocated for the use of peer review, which has been shown to improve students' ability to give and receive criticism[2], as well as increase collaborative learning in the classroom[3]. Multiple studies comparing peer and teacher assessment have unpacked the benefits of peer review[4]. Adding peer review to instructor review increases the overall quantity of feedback received by students[5], with the most benefit being derived when feedback is provided by multiple peers[6]. Peer feedback has been found to be beneficial even in cultures that emphasize the authority of the teacher[7].

1.1 Peer review in engineering design

More recently, several implementations of capstone design courses (as well as design courses in junior and intermediate years) at various universities have reported incorporating some form of peer review. The trend is in part influenced by a successful tradition of the design critique in architecture programs[8-11], where student peers, in addition to course instructors and expert professionals are invited to critique design artifacts. Peer review is also a common industry practice; in organizations, design reviews occur often and involve not just clients and supervisors but also colleagues. In this context, peer-to-peer review is crucial to design success. The quantity and type of peer review that is made possible in engineering design classes vary depending on the implementation, with reported examples ranging from inter-team assessment of oral presentations[12] to written review of design documents[13,14] and artifacts[15].

We have previously reported on an intensive face-to-face implementation of peer review in a management engineering capstone design program[16,17]. In biweekly meetings students critiqued various aspects of other teams' design projects, including oral presentations, documents, and artifacts in an informal and supportive atmosphere. The format encouraged students to share ideas between groups, helped them improve how they communicated their problem and solution, and potentially led to improved design outcomes by providing multiple opportunities for receiving feedback and refining the design. While students were asked to report on the helpfulness of feedback from both the course instructor and student peers, the results were not conclusive[17,18]. More generally, while there are many studies comparing peer and instructor feedback in other domains such as English writing, rigorous characterization and comparison of peer and expert feedback in engineering design is limited.

Taking a grounded theory methodological approach[19], the wider aim of this research is to analyze actual feedback provided by students and course instructors in design review meetings that utilize peer review and to expose the characteristics of each, with the ultimate intent of evaluating and comparing their benefits and suitability. The focus of *this* paper is on the first step of this process, which is *the development of a suitable typology for characterizing instructor and* *student feedback*. Once feedback comments can be appropriately coded, accurate comparisons can be made between student and instructor feedback and useful conclusions derived.

The rest of the paper is structured as follows. In Section 2, we seek to determine useful existing typologies of feedback, looking at both differences in the focus of feedback given by engineering experts and novices (Section 2.1), as well as on how feedback can be structured more generally (Section 2.2). Then, in Section 3, after introducing the general context of the study from which data is collected (Section 3.1), we delve into the development of a two-dimensional typology of feedback that accounts for both its *content* (Section 3.2) and *form* (Section 3.3). To illustrate the proposed typology, we also provide numerous examples of actual feedback comments provided by students and the instructor. We conclude this paper with a general discussion and a plan for how the developed feedback typology will be used to categorize and analyze the rich feedback data collected thus far (Section 4).

2. Review of existing typologies of feedback

2.1 The design process

Design, as a high form of problem solving[20], is generally regarded as essential knowledge for all of the professions. Indeed Simon[21] reminds us that design is the core of all professional training, and that "*it is the principal mark that distinguishes the professions from the sciences*"(p.111). It is essential that the teaching and learning of design, and more importantly, the development of design expertise, be understood. As Jack Alford, co-founder of the now highly regarded engineering clinic sequence at Harvey Mudd College suggested, "*I gained the idea that engineering [design] was like dancing; you don't learn it in a darkened lecture hall watching slides; you learn it by getting out on the dance floor and having your toes stepped on*"[22]. Even at this, there are general prescriptive moves that are defined for each type of dance undertaken. What about design processes then?

An early accepted model of design was proposed by Asimow[23]. He divided the process into three (3) classes - analysis, synthesis and evaluation – and identified a feedback process between evaluation and analysis. Howard, Culley and Dekoninck[24] considered over 100 different processes of which 42 were tabulated for comparative purposes. Within these processes, they identified when and where the process of creativity occurs. More recently, in a literature review, Gericke and Blessing[25] consolidated the current findings from different comparisons of design process models from different disciplines. While they find consensus on a generic core of common stages, they note that a generic applicable (prescriptive) approach does not exist and that models need interpretation and adaptation depending on the context. However they do identify *stages*, defined as subdivisions of the design process based on the state of the product under development (i.e. problem definition, conceptual design, detailed design). They also identify *activities*, defined as much finer divisions than stages, covering a shorter period of time. They note that a typical characteristic of an activity is that it occurs several times in one process.

Some examples of activities include generating [concepts], evaluating and selecting. Finally they define *strategies*, which are sequences in which design stages and activities are planned or executed. These represent possible ways to implement the design process, and include cyclic, stepwise, iterative, decomposing and abstracting/concretizing approaches.

The most theoretical and cited treatment of the design method is given by Gero[26]. He proposes a Function-Behaviour-Structure framework, where *functions* describe the nature of the required design (i.e., "what it is for"), *behaviours* describe the attributes that are derived or expected to be derived of the object (i.e., "what it does"), and *structure* describes the components of the design and their relationships with one-another (i.e., "what it is"). Key features of this theory are the identification of *reformulation* processes within *structure-structure*, between *structure-behaviour*, and between *structure-function*.

While the research in design methods remains very informative, in practice there are implementations that are highly context, application and business-specific. Some design processes are expressed in standards, while others are expressed within standard operating procedures and quality management processes. These practical implementations recognize the importance of containing the design process within a practical framework of project management and planning methods. As such, Karuppoor, Burger and Chona[27] express a design process model that attempts to incorporate some practical elements with the express intent of finding an effective means of teaching this process to novice engineers. They illustrate the effectiveness of their process for maximizing the potential for successful design outcomes and innovation by giving two (2) sets of students a toy design task. One set of students were not formally exposed to this methodology and another set of students were exposed to the particular methodology. The results suggested that following their design methodology increased the probability of achieving higher-quality designs.

Also likened to chess, teaching of design usually begins with lectures, where the terminology and elements of the design process are introduced and elaborated. However after this, the 'chess games', or specific design projects that are undertaken by student teams, require application and situationally-specific teaching treatments. Teaching must include 'facilitation' or coaching approaches, and no one common lecture-based statement of generalized instruction can hope to address the variance in situations being experienced by each specific design project being undertaken by the teams of students in the course for authentic design situations. So then, how do experts take these generalized theories and practical prescriptions of design process methods, and apply them to specific situations? How do novices approach design problems? How can this expertise be taught or facilitated? How do design reviews contribute to the teaching and learning of the application of design processes and methods? What is the role of feedback in design reviews for the teaching and learning of design?

In a review on the nature of design expertise, Cross[28] compares and contrasts expert versus novice performance and describes the behaviour of expert designers. He emphasizes that expertise develops over time and through deliberate practice and feedback, as in chess, music, and sports performance. Expertise requires a willingness to work (conative performance) and a period of sustained involvement. In his comparison of expert versus novice designers, he notes that novices exhibit a so-called ‘depth-first’ approach to problem solving, whereas experts use strategies and approaches that tend to be predominately ‘top-down’ and ‘breadth-first’. In contrast to chess, authentic design problems are initially ill-defined. In these cases Cross notes that expert designers use explicit problem decomposing strategies that novices appear not to possess. He also notes other important behavioral and problem solving approaches that are different, including experts’ abilities to ‘mentally stand back’ from the problem, to ‘structure’ and ‘frame’ problems effectively, and to ‘co-evolve’ both problem and solution spaces. Cross notes that processes of formulating and ‘framing’ the problem are mostly identified as key features of design expertise.

Similarly, in his observational studies of outstanding architects, Lawson[29] noted that they possessed the ability to ‘work along parallel lines of thought’, and to possess the ‘bravery’ to keep these lines of thought parallel for rather longer than might seem reasonable to the inexperienced designer.

Finally, in an experiment that sought to directly compare experts and novices, Atman et al.[30] compared the process of designing a playground exhibited by 19 practicing engineers to that of 26 freshmen and 24 senior students, as also reported in a prior study[31]. Participants were asked to ‘think aloud’ as they solved the design problem. Recordings of these sessions were later transcribed and the length of time spent on each design stage was measured. The study found that experts spent more time than senior students on each stage of the design, and in particular the problem scoping stage, including the activities of problem definition and information gathering.

2.2 Characteristics of feedback

Research in higher education has proposed that feedback must be effective in all levels of student learning: cognitive, motivational, and behavioural. Good feedback promotes student reflection and self-learning by helping clarify learning goals and teacher expectations, facilitating student self-assessment, delivering high-quality information to students about their progress, encouraging teacher-student dialogue, improving student motivation and self-esteem, bridging the gap between current and expected performance, and ultimately improving teaching.[32]

Narciss[33] identifies two components of feedback – the *evaluative part*, which assesses the quality of the answer, and the *informational part*, which provides direction for progress. Shute[1] reviews a similar model, according to which feedback contains both *verification* and *elaboration* components. A more informative feedback is found to be related to better performance, and in some cases, better motivation[33]. Whether or not more information in the feedback improves student motivation depends on the student’s confidence in their own abilities (or self-efficacy)[34].

Different frameworks in different domains have categorized feedback along a variety of (sometimes overlapping) axes. Common examples of typologies organize feedback according to dimensions such as scope and specificity, and include a variety of other feedback types, such as summaries, explanations, and praise[35]. Below we review some of the main themes found in the literature.

Perhaps one of the more common ways used to categorize feedback is according to its *specificity*, though the classification of feedback in this dimension is far from specific[1]. In the domain of learning a second language, for example, a basic distinction has been made between corrective feedback that is *direct* (i.e., telling students exactly where the problem is and how to fix it) versus *indirect* (i.e., point out that there is an error without correcting it)[36]. Similarly, in the domain of English writing, Cho, Schunn and Charney[37] identified *directive* (i.e., specific suggestions for improvement) and *non-directive* (i.e., non-specific suggestions for improvement that could apply to any paper) types of feedback. Generally, while direct corrective feedback can be an appealing alternative when time is limited, indirect feedback can be better 'customized' to specific students' learning styles and improves student learning by allowing them to self-correct[38]. A similar dimension to specificity is also the degree of helpfulness of the feedback; for example, in a study with 5th graders creating science questions, Yu and Wu[39] described four levels of descriptive comments: general, specific identification of strengths and weaknesses, the latter plus identification of areas for improvement, and explicit suggestions for how improvements might be achieved.

The evaluative (or verification) component of feedback has sometimes been further broken down as either p*raise* (i.e., encouraging comments) or c*riticism* (i.e., pointing out weaknesses without suggesting an improvement). In contrast, the *summary*-type feedback comments (i.e., restating the main points of a portion or the whole work) usually lack an evaluative component altogether.[37]

As one moves from the context of providing feedback in the domain of learning writing and second language skills to the context of the architecture and engineering design review, new feedback typologies begin to emerge. In architecture programs, the activity of critique is central to the design pedagogy[9]. A study of the type of critique given by experts and novices in the architecture studio uncovered up to nine types of feedback, with the five most frequent being comments that were *judgmental* (i.e., conveying an assessment in an evaluative tone), *process oriented* (i.e., related to the student's design approach), *brainstorming* (i.e., related to future imagined possibilities), *interpretative* (i.e., making sense of what was presented), or a *direct recommendation* (i.e., giving specific advice)[40].

There are few discussions of feedback typology in engineering education research. In many cases, studies touch on the effectiveness of different types of feedback in computer-based or training scenarios. In one such example, feedback is categorized according to three types: *outcome* (i.e., providing specific information about achieved performance), *process* (i.e., providing advice without specific performance information), and *normative* (i.e., providing a performance comparison to others), with process feedback being the most effective[41].

A final related dimension of feedback that we review here is that of length/complexity. While longer feedback can be more informative, more complex feedback can be more difficult to understand by the novice; however, it is not clear whether the effect of complex feedback is entirely negative[1]. Studies have found that the length of feedback and the number of comments is larger for experts than for student peers, with experts providing more directive and non-directive feedback than student peers[37]. Student peers provide more praise comments, while experts provide the fewest summary comments[37]. Non-directive feedback results in more complex repairs to students work, whereas directive feedback results in mostly surface improvements[5].

3. Current investigation

While the ultimate objective of this research is to compare instructor and student feedback that is delivered in the face-to-face context of the design review in capstone design courses, the objective of this *preliminary* investigation is to characterize the feedback in a manner that enables that comparison. In the next sections, we describe the context in which the data is gathered and then outline a developed two-dimensional typology to characterize student and instructor feedback.

3.1 Data collection

The study was conducted in a management engineering capstone design course at the University of Waterloo. This course was the first in a two-course series that comprises the capstone design project in this program. By the end of the 13-week course, students were expected to form groups, select a project topic, research and gather information on the design problem, identify the design requirements and specifications, produce at least three conceptual designs and finally propose and describe a low-fidelity prototype of a chosen design for implementation. During the term, teams were expected to submit four major deliverables coinciding with major design stages. The class of fifty-five students self-enrolled in fourteen project teams, with all but one team having four members. Each team was able to source their project topic from a variety of sources, including industry projects and faculty-proposed projects sourced by the course instructor, industry projects the students secured through their contacts with former co-op employers, and design problems students identified themselves.

Students attended formal lectures on engineering design in just six of the thirteen-week course. Most of the rest of class time was structured around biweekly design review meetings, which in this course were called progress update meetings (PUMs), as shown in Table 1 below.

Table 1. Summary of capstone course schedule

Week	**Course Activity**
1 - 4	Lectures covering the following topics: • Course orientation and teamwork workshop • Need analysis, conducting research, project management • Safety, ethics, and other requirements • Client relationship management
5 - 6	PUM #1 – focused on need analysis/specifications
7	Lecture on conceptual design
8 – 9	PUM #2 – focused on specifications/conceptual design
10	Lecture on prototype design
11 - 12	PUM #3 – focused on conceptual design/preliminary design
13	Final presentations

PUMs were formatted in two ways:

1. The instructor-only format was a 40-minute meeting in which a single team presented their progress to the course instructor, followed by a discussion period in which the instructor asked questions and provided feedback.
2. The mixed-review format was a 80-minute meeting in which two teams presented their progress to each other and to the course instructor, followed by a discussion period in which each team was questioned and received feedback from both the instructor and the other team in attendance.

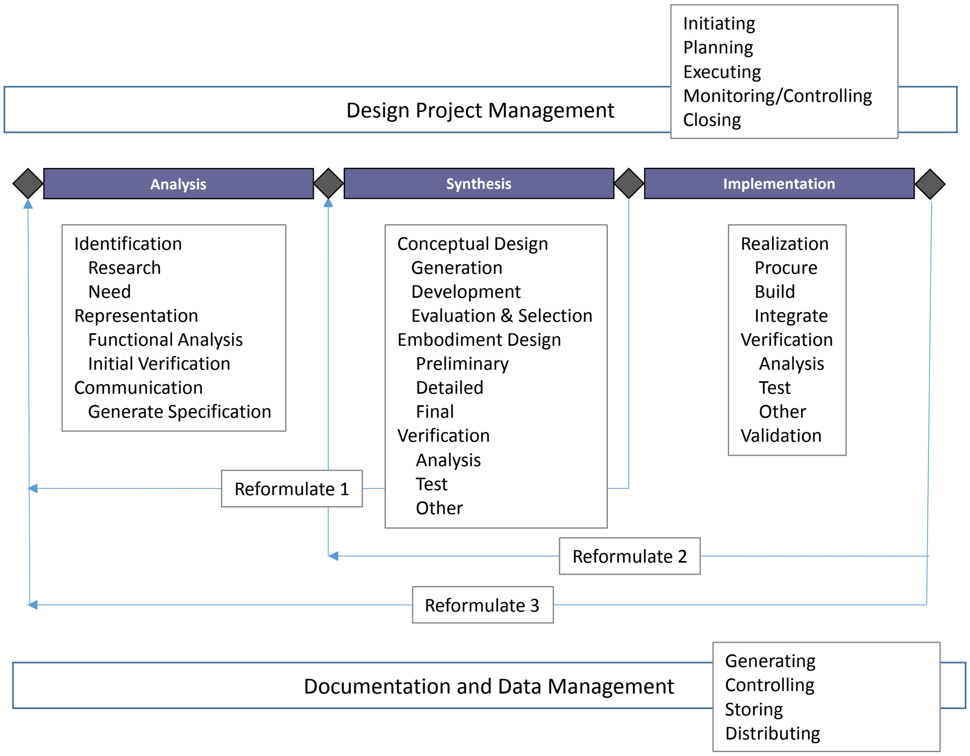
Each team participated in three PUMs: one in the instructor-only format and two in the mixed-review format. For all teams, the third PUM was held in the mixed-review format. The first and second PUM were structured such that eight of the teams had their sole instructor-only meeting in the first PUM whereas the remaining six had it in their second PUM. This schedule was chosen for two reasons. First, it was important to test both meeting formats in order to observe whether instructor feedback changed depending on the context. In the case of the mixed-review format, the instructor is not only reacting to the presented material but also to the feedback provided by the students in the meeting. Thus, it is plausible that the instructor's feedback in this context may differ - in quantity, content and type - from the feedback they would have provided if the meeting was in the instructor-only format. Second, the sequence in which the instructor-only and mixed-review meetings are scheduled might introduce order effects. For example, student feedback might be of better quality in the second PUM, compared to the first PUM because by then students will have had a chance to accustom themselves to the general design review meeting format and objectives. All PUMs were video recorded, resulting in twenty-eight hours of video, which is being transcribed using Rev, a professional transcribing service. The intention is to categorize and then analyze all feedback comments for the purpose of comparing student and instructor feedback.

In the two following sub-sections we outline a new proposed two-dimensional typology of feedback. The first dimension concerns the *content* of feedback, which is the design stage or activity on which the feedback is focused. The second dimension concerns the *form* that feedback takes.

3.2 The content of feedback

The engineering design process model we used (as illustrated in Figure 1) incorporates both theoretical bases and practical accommodations. The most important departure from most models is the placement of the design project management and documentation development as parallel supporting processes[42]. In reality, these two (2) processes occur simultaneously with stages and at varying degrees depending on the project complexity and design stage. Important reformulation processes are incorporated at the stage/phase level. The coding classifications have been carefully selected in order to optimize the classification effort while attempting to inform us of feedback activity nature and level. For example, we recognize the importance of need analysis and the emphasis that experts place on this stage verses novices, and so the important coding classifications of problem identification, representation and communication are prominent in our model. Additionally, the verification classification is available at each stage, as this reflects best design practice.

Figure 1. A generalized engineering design process model with coding classifications



As mentioned, the **need analysis** stage is regarded as the most important part of the design process. It is a process of problem finding and representing as opposed to problem solving. It is divided into three (3) phases: identification, representation and communication. These divisions are based on Karuppoor et al.[27]'s design philosophy, emphasizing the key skills of *questioning* and *abstraction*. In the problem identification phase, the two (2) key activities we define are researching and expressing the need. Researching is an important skill, as this is where requirements are collected from various stakeholders, and benchmarks, technologies, and the states-of-the-art are determined from various knowledge domains. They place importance on reducing the problem essence in terms of the *real need*, expressed as the combination of the primary function and primary constraint. Problem representation consists of a functional analysis, including expressing the problem in terms of functions, non-functions and constraints. This may also include arranging the functions in a useful structure(s). Finally, need analysis culminates with the important phase of communication in terms of an engineering design specification. A useful and valid engineering design specification will contain key elements, such as number, attribute description, value, relation between value and attribute, units of measure, and verification method planned.

We have defined the **synthesis** stage of the design process as having three (3) main phases: conceptual design, embodiment design and design verification. Conceptual design includes the activities of generation of ideas, elaboration and development of the ideas into concepts that are meaningful, useful and practical, and finally evaluation and selection of one or more concepts for further development. Embodiment design is expressed as a series of design refinement activities, where the concepts are expressed in scaled, coded and practical expressions, useful for implementation. Design verification is often a key phase of this part of the design process, since risk can be reduced substantially by ensuring the design meets the engineering design specification communicated in the need analysis stage. Typically verification at this stage is focussed on analyses, simulations and calculation, but low to medium fidelity prototypes are commonly used as well.

The **implementation** stage includes phases of realizing, verifying and validating the design solution in intended or simulated use contexts. Typical activities include procuring parts, building, assembling, integrating, and performing initial functional testing. Design verification would include formal activities to prove that the design meets all of the engineering design specifications. In contrast, validation would place the design solution in the users' hands and in authentic use contexts, thereby offering opportunities to determine whether the need analysis previously performed was valid and accurate.

Reformulation activities have also been defined in our model since these represent important and authentic activities in any design undertaking. Reformulation within a stage has not been classified but obviously might exist.

The process of **design project management** includes activities as defined by the PMBOK[43] for a project, such as initiating, planning, executing, monitoring and controlling, and closing a project. Examples of activities relating to this overarching stage in the process would be tools and techniques that utilize work-breakdown structures to determine project scope and schedules.

Finally, the maturation of **data and documentation** features activities such as generating, controlling, storing and distributing data. The data would typically include software code, drawings, project management data, and so on.

Table 2 below presents the classification elements from this model in tabular form along with illustrative comments from our data. It was difficult for us to locate an appropriate illustrative comment for the third reformulation process, possibly because the data collected covers largely stages related to analysis and synthesis.

Table 2. The content of feedback: design stages/activities and examples

Content of feedback	***Example***
Design project management	*"...after talking to our advisor, we realized that maybe our scope might be too large for this project. We're currently in the middle of negotiating our project schedule with [client] so we should hopefully have that done sometime this month."*
Analysis	
Identification	*"It's not clear ... Let's start with a basic question a person will essentially ask you. What is the need statement?"*
Representation	*"... think about the three different main functionality, right? The fact is first it's going to be open source so you talk about the open source designs that you have in mind. Then, the second functionality is that it's customizable. To me, it'd be nice to also see what ways you see in the interface that makes it customizable."*
Communication	*"Eventually, we're going to design a new system according to these specifications."*
Synthesis	
Conceptual Design	*"So, you have those four conceptual designs, or three and then one. Have you guys considered maybe a little bit of a hybrid?"*
Embodiment Design	*"I will definitely make an effort to do more preliminary design before the end of this semester."*
Verification	*"…we came up with some conceptual designs and a prototype for one of them."*
Implementation	
Realize	*"I think you can use it but it requires a lot of time and programming skills to build that kind of software."*

Verify	*"In addition to these different simulation results we also rated them based on what requirements they filled."*
Validate	*"So, the whole validation, verification aspect of the tool .. the goal of that whole thing is to squash a lot of these issues by validating the student's email,"*
Reformulation 1 (Synthesis ⇨ Analysis)	*"So far, as an update to what we've done our problem analysis and requirements have been updated since the conceptual design stage."*
Reformulation 2 (Implementation ⇨ Synthesis)	*"Maybe if you have your earphones on it will tell you, "Okay, turn left here or there's a slight turn here." I'm not sure how complex that will be to build and how much time it will take, but we're going to try to do that one again."*
Reformulation 3 (Implementation ⇨ Analysis)	Data not found
Documentation & Data Management	*"We are working on a low, medium and high fidelity prototype to deliver a working system, and that working system needs to have documentation so that this solution can continue to grow."*

3.3 The form of feedback

Based on the reviewed literature earlier in Section 2.2 of this paper, it is clear that there are many typologies in use in different domains - especially in the domain of language education - for categorizing the *form* that feedback can take. Drawing from those existing typologies, we define three components: interpretation, evaluation, and recommendation.

Interpretation is the component of feedback in which the reviewer simply summarizes the information that is sent by the design team. The reviewer's goal is to ensure that they have clearly understood what is presented. In this context, clarification questions are also categorized as interpretative; the reviewer's aim is to clarify their understanding of the message. Interpretive questions can also be probing in nature; the reviewer's aim could be to expand their understanding, beyond what is already presented. In summary, interpretive feedback can come in the form of a summarizing statement or as a clarification or probing question.

Evaluation is the component of feedback in which the reviewer provides a judgment about what is presented. Here we envision that judgment as closely related to an expected target. In other words, whether the judgment is positive, negative, or neutral, is simply an assessment of the distance between the current state of the design and the state the design ought to be in. Note that both states are subject to the reviewer's perception. First, the perceived current status of the design is based on the reviewer's understanding of the presented information; interpretive statements and questions are intended to ascertain that the current state has been accurately pinpointed. Second, the expected state of the design is also subject to the reviewer's perception of the type and difficulty of the design project, the team's skill, the elapsed time in the project, as well as the reviewer's own design experience and a host of other factors. The expressed evaluation can take both explicit and implicit forms. When implicit, the evaluation can usually be extracted from the content of the recommendation component of the feedback (see below). In other words, the content of the recommendation provided also packs an implicit evaluation of what has been presented.

Finally, the **recommendation** component provides further elaboration/information about what the team can do to achieve a desired state. In the case when the evaluation was negative (i.e., the current state is perceived to be lower than the expected state), the recommendation will provide steps for achieving an expected target performance. In the case when the evaluation is positive (i.e., the current state surpasses the expected state), the recommendation will either 'raise the bar' and set a new performance target (or desired state) for the team, or simply give the team an opportunity to re-scope the project so that additional effort (above expectation) is not needed in future milestones.

Feedback comments rarely contain all three components (interpretation, evaluation, and recommendation). In Table 3 below we summarize some of the various types of *forms* feedback and illustrate the permutations with examples from our already and transcribed data.

Table 3. The form of feedback: types and examples

Form of feedback	***Example***
Interpretation only	Posed as a statement: *"Okay. So material handling is one of the costs that you consider. These [slides] were the description of what that entails."* Posed as a clarification question: "*So, sorry. Just so I understand. Is this a concept? These six steps?*" Posed as probing question: *"Are the hospitals pretty far away from each other? Is transportation a big factor?"*
Evaluation only	Positive evaluation (praise): *"I feel like you guys have it really well thought out. It's really great."* Negative evaluation (criticism): *"You guys got the same feedback at the last PUM too, from me [and yet, I don't see an improvement]"*
Recommendation only	*"Can you guys use simulation data like, can you just create test days and work with it?*
Evaluation + Recommendation	*"I got lost a little bit. [In the future you can explain this a bit better]: how does material flow from one place [to the other]?"*

Interpretation + Recommendation	*"Can you go back to your [previous] slide? You said that if the inventory goes below [X] they will [make an emergency order]. Why not just order a normal delivery that will cut down on that?*
Interpretation + Evaluation + Recommendation	*"Earlier we discussed geopolitical issues. [But]a different kind of hospital might have a different [blood ordering] profile. How would that affect the models?"*

4. Discussion and future work

The purpose of this preliminary paper was to develop a new typology that could be used to characterize feedback in engineering design reviews. The developed two-dimensional typology captures both the focus of feedback in terms of the design stage or activity (i.e., its content) and the form that the feedback takes. This typology will be applied and refined in the wider research project, which seeks to conduct a rigorous comparison of peer and instructor feedback.

This new line of inquiry presents several advantages. Overall, the wider research project departs from prior reported studies in several important ways. First, the examination of expert and novice feedback is conducted in an authentic context, where students and instructors are engaged in reviewing students' actual capstone design projects. Second, the study captures spoken feedback given to students while they present their progress and demo their designs, rather than relying on more secondary sources such as written reviews. Third, and more specifically to *this* paper, we have developed a new typology that characterizes feedback along two important dimensions that capture both the design context and the variability in feedback types.

It is observed that the qualitative data that we have collected through the video-recordings of design reviews, though rich and authentic, present a significant challenge in terms of being adequately coded into the pre-defined categories of our typology. That challenge was made clear as we sought to illustrate our developed categories with actual examples in Tables 2 and 3. Interpretation of natural text can be a very complicated process, requiring multiple iterations and significant reflection. While grounded theory provides us with a formalized methodology through which to approach the data analysis[19], it also (almost) guarantees that at the end of the process, the feedback typology that ultimately emerges may have little resemblance to the one that we have so carefully developed here.

References

1. V. J. Shute, "Focus on formative feedback," Review of Educational Research, vol. 78, no. 1, pp. 153-189, 2008.

2. H. Sondergaard and R. A. Mulder, "Collaborative Learning through Formative Peer Review: Pedagogy, Programs, and Potential," Computer Science Education, vol. 22, no. 4, pp. 343-367, 2012.
3. K. Willey and A. Gardner, "Investigating the Capacity of Self and Peer Assessment Activities to Engage Students and Promote Learning," European Journal of Engineering Education, vol. 35, no. 4, pp. 429-443, 2010.
4. N. Falchikov and J. Goldfinch, "Student peer assessment in higher education: A meta-analysis comparing peer and teacher marks," Review of Educational Research, vol. 70, no. 3, pp. 287-322, 2000.
5. K. Cho and C. MacArthur, "Student Revision with Peer and Expert Reviewing," Learning and Instruction, vol. 20, pp. 3328-338, 2010.
6. K. Cho and C. D. Schunn, "Scaffolded Writing and Rewriting in the Discipline: A Web-Based Reciprocal Peer Review System," Computers and Education, vol. 48, no. 3, pp. 409-426, 2007.
7. M. Yang, R. Badger and Z. Yu, "A comparative study of peer and teacher feedback in a Chinese EFL writing class," Journal of Second Language Writing, vol. 15, no. 3, pp. 179-200, 2006.
8. S. M. Dinham, "Research on Instruction in the Architecture Studio: Theoretical Conceptualizations, Research Problems, and Examples," in Presented at the Annual Meeting of the Mid-America College Art Association, 1987.
9. S. Kuhn, "Learning from the Architecture Studio: Implications for Project-Based Pedagogy," International Journal of Engineering Education, vol. 17, no. 4 & 5, pp. 349-352, 2001.
10. R. Bannerot and A. Patton, "Studio Design Experiences," in Proceedings of the 2002 ASEE Gulf-Southwest Annual Conference, The University of Louisiana at Lafayette.
11. Y. Oh, S. Ishizaki, M. D. Gross and E. Y.-L. Do, "A Theoretical Framework of Design Critiquing in Architecture Studios," Design Studies, vol. 34, pp. 302-325, 2013.
12. L. J. McKenzie, M. S. Trevisan, D. C. Davis and S. W. Beyerlein, "Capstone Design Courses and Assessment: A National Study," in Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition, 2004.
13. D. Nicol, A. Thomson and C. Breslin, "Rethinking Feedback Practices in Higher Education: A Peer Review Perspective," Assessment & Evaluation in Higher Education, vol. 39, no. 1, pp. 102-122, 2014.
14. R. Pimmel, "Cooperative Learning Instructional Activities in a Capstone Design Course," Journal of Engineering Education, vol. 90, no. 3, pp. 413-421, 2001.
15. V. Garousi, "Applying Peer Reviews in Software Engineering Education: An Experiment and Lessons Learned," IEEE Transactions on Education, vol. 53, no. 2, pp. 182-193, 2010.
16. A. Hurst, "Joint progress update meetings in capstone design courses: Encouraging peer review and cooperative learning," in Proceedings of the 2014 Capstone Conference, Columbus, Ohio, 2014.
17. A. Hurst and O. G. Nespoli, "Peer review in capstone design courses: An implementation using progress update meetings," International Journal of Engineering Education, vol. 31, no. 6(B), pp. 1799-1809, 2015.
18. A. Hurst and O. G. Nespoli, "Student perceptions of value of peer and instructor feedback in capstone design review meetings," in Proceedings of the 2016 Capstone Conference, Columbus, Ohio, 2016 [to appear].
19. J. Corbin and A. Strauss, Basics of Qualitative Research: Techniques and Procedures for developing grounded theory, 3rd ed., Sage Publications, 2008.

20. D. H. Jonassen, "Toward a design theory of problem solving," Educational Technology Research and Development, vol. 48, no. 4, pp. 63-85, 2000.

21. H. A. Simon, The sciences of the artificial, Cambridge, MA: MIT Press, 1996.

22. Harvey Mudd College, "Engineering Clinic Guidelines," 2011.

23. M. Asimow, Introduction to design, vol. 394, Englewood Cliffs, NJ: Prentice-Hall, 1962.

24. T. Howard, S. Culley and E. Dekoninck, "Creativity in the engineering design process," in 16th International Conference of Engineering Design (ICED'07), Paris, France, 2007.

25. K. Gericke and L. Blessing, "Comparisons of design methodologies and process models across disciplines: A literature review," in 18th International Conference on Engineering Design (ICED11), Copenhagen, Denmark, 2011.

26. J. S. Gero, "Design prototypes: A knowledge representation schema for design," AI Magazine, vol. 11, no. 4, pp. 26-36, 1990.

27. S. S. Karuppoor, C. P. Burger and R. Chona, "Designing better," in Proceedings of the 2002 ASEE Gulf-Southwest Annual Conference, 2002.

28. N. Cross, "Expertise in design: An overview," Design Studies, vol. 25, no. 5, pp. 427-441, 2004.

29. B. Lawson, Design in mind, Architectural Press, 1994.

30. C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg and J. Saleem, "Engineering design processes: A comparison of students and expert practitioners," Journal of Engineering Education, vol. 96, no. 4, pp. 359-379, 2007.

31. C. J. Atman, J. R. Chimka, K. M. Bursic and H. L. Nachtmann, "A comparison of freshman and senior engineering design processes," Design Studies, vol. 20, no. 2, pp. 131-152, 1999.

32. D. J. Nicol and D. Macfarlane-Dick, "Formative assessment and self-regulated learning: a model and seven principles of good feedback practice," Studies in Higher Education, vol. 31, no. 2, pp. 199-218, 2006.

33. S. Narciss, "Motivational effects of the informativeness of feedback," in Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada, 1999.

34. S. Narciss, "The impact of informative tutoring feedback and self-efficacy on motivation and achievement in concept learning," Experimental Psychology, vol. 51, no. 3, pp. 214-228, 2004.

35. M. M. Nelson and C. D. Schunn, "The nature of feedback: how different types of peer feedback affect writing performance," Instructional Science, vol. 37, pp. 375-401, 2009.

36. R. Ellis, "A typology of written corrective feedback," ELT Journal, vol. 63, no. 2, pp. 97-107, 2009.

37. K. Cho, C. D. Schunn and D. Charney, "Commenting on writing: Typology and perceived helpfulness of comments from novice peer reviewers and subject matter experts," Written Communication, vol. 23, no. 3, pp. 260-294, 2006.

38. R. Yoshida, "Teachers' choice and learners' preference of corrective feedback types," Language Awareness, vol. 17, no. 1, pp. 78-93, 2008.

39. F.-Y. Yu and C.-P. Wu, "Predictive effects of online peer feedback types on performance quality," Educational Technology & Society, vol. 16, no. 1, pp. 332-341, 2013.

40. D. P. Dannels and K. Norris Martin, "Critiquing critiques: A genre analysis of feedback across novice to expert design studios," Journal of Business and Technical Communication, vol. 22, no. 2, pp. 135-159, 2008.

41. R. S. Astwood, W. L. Van Buskirk, J. M. Cornejo and J. Dalton, "The impact of different feedback types on decision-making in simulation based training environments," in Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting, 2008.

42. J. Ochs, 5-Step Product Development Process, Private communication, 2008.

43. Project Management Institute, A guide to the project management body of knowledge (PMBOK® Guide), 5th ed., 2013.