Directing Convergent and Divergent Activity through Design Feedback.

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Abstract
Design education across design disciplines prioritizes project-based courses to support student learning about design processes and strategies (Eastman, Newsstetter, & McCracken, 1999; Smith, Sheppard, Johnson, & Johnson, 2005). Success in teaching these courses relies on the ability of instructors to mentor and guide students’ design paths, allowing students some freedom to determine design decisions on their own, while facilitating a structure where they can learn successful design strategies.

Disciplines
Higher Education | Industrial and Product Design | Interdisciplinary Arts and Media

Comments
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Directing Convergent and Divergent Activity Through Design Feedback

Shanna R. Daly
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Introduction

Design education across design disciplines prioritizes project-based courses to support student learning about design processes and strategies (Eastman, Newstetter, & McCracken, 1999; Smith, Sheppard, Johnson, & Johnson, 2005). Success in teaching these courses relies on the ability of instructors to mentor and guide students' design paths, allowing students some freedom to determine design decisions on their own, while facilitating a structure where they can learn successful design strategies. Little research has investigated how feedback directs students with regards to divergent and convergent design activities. Successful development of an idea involves both types of thinking, meaning there are times when designers diverge to see new possibilities, generate multiple ideas for consideration, and take risks, and times when designers converge to analyze and narrow down problem criteria and ideas (Brophy, 2001; Cropley, 2006; Cross, 2003; Dym & Little, 2004; Guilford, 1984; Liu, Bligh, & Chakrabarti, 2003). While overall design processes and the paths toward a final design artifact are convergent in nature, process models represent both types of design thinking throughout (e.g., Banathy, 1996; Cross, 2000). However, the choices created (divergent thinking) may get less broad, and the choices may need to be evaluated and executed (convergent thinking) more frequently as designs move toward final products.

Many disciplines engage in design thinking, although they each use unique terms to describe it (Goel & Pirolli, 1992). For example, a musical score is composed, a science experiment is developed, or a dance work is choreographed. Design studies comparing multiple disciplinary perspectives allow for design disciplines to learn from one another (e.g., Cross & Roozenburg, 1992; Daly, 2008; Daly, Adams, & Bodner, 2012; Goldschmidt & Rodgers, 2013; Lloyd & Scott, 1994; Purcell & Gero, 1996; Yilmaz, Daly, Seifert, & Gon-
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zalez, 2010, 2013). Our work explored instructor feedback in dance choreography, industrial design, and mechanical engineering. While the content of the design projects was unique to the discipline, students engaged in design thinking and were responsible for generating and evaluating ideas and developing those ideas into final design outcomes. Our goals were to investigate if feedback indicated direction to students to engage in either convergent or divergent design activities, and to translate our findings to design education and research implications.

Background

Divergence and Convergence in Design Processes

Design thinking requires designers to explore both the problem and solution space and develop and evaluate promising pathways (Dorst & Cross, 2001; Maher, Poon, & Boullanger, 1996; Sheppard, 2003). Designers move through cycles of idea development, idea selection, and more idea generation to eventually determine a final design. These iterations require divergent thinking for creating choices to consider, and convergent thinking for narrowing and selecting from those choices.

In concept generation, a variety of ideas is considered a key component of success (Jansson & Smith, 1993; Nelson, Wilson, Rosen, & Yen, 2009; Shah, Smith, & Vargas-Hernandez, 2000; Srinivasan & Chakrabarti, 2010), as is idea novelty (Dean, Hender, Rodgers, & Santanen, 2006; Linsey, 2007; Peeters, Verhaegen, Vandevenne, & Duflou, 2010; Shah et al., 2000), where in the solution space of all potential solutions for a problem, designers create concepts that are not considered "obvious." Fixation on a first or existing idea prematurely limits the design space and can impede novel ideas (Cross, 2001; Jansson & Smith, 1991; Linsey et al., 2010; Purcell & Gero, 1996). Going beyond obvious ideas requires divergent thinking, which includes shifting perspectives, seeing new possibilities, being unconventional, combining the disparate, taking risks, and producing multiple answers (Basadur, Graen, & Scandura, 1986; Basadur & Hausdorf, 1996; Cropley, 2006; Runco, 1991, 1993; Silvia et al., 2008). While design processes often have a phase labeled "concept generation," concept generation happens throughout a design process, when one encounters a decision point and creates multiple options for the decision. Engineering students have been shown to struggle to diverge during design work, especially in mid to later phases of design (Crismond & Adams, 2012; Kramer, Daly, Yilmaz, & Seifert, 2014; Kramer, Daly, Yilmaz, Seifert, & Gonzalez, 2015).

While divergent thinking is crucial to successful design processes, convergent thinking is also critical, as it determines the direction of the design embodiment stage (Guilford, 1967; King & Sivaloganathan, 1999). Convergent thinking refers to seeking a single or best solution through identifying familiar solutions, testing, validating, and synthesizing existing information (Cropley, 2006; Guilford, 1967; Runco, 2007; Weisberg, 1999). A variety of convergent thinking tools exist to support evaluation, synthesis, and selection of promising ideas (Aurand, Roberts, & Shunk, 1998; Mullur, Mattson, & Messac, 2003; Otto, 1995; Pahl & Beitz, 1996; Pugh, 1996; Thurston & Carnahan, 1992; Ullman, 1992; Wang, 1997).
Design processes, overall, generally flow from divergent to convergent thought; however, design process models represent smaller waves of divergent thinking throughout the process (Banathy, 1996; Cross, 2000) (see Figure 1), thus we expected our data set would provide opportunities to analyze for divergent and convergent feedback direction throughout students’ design process. For example, in early design work, divergent thinking may be suggesting many diverse ideas, but in the mid to later phases, divergent thinking may be suggesting multiple ways to achieve specific characteristics of the chosen concept. Even at the very last stages of design, decisions have to be made, and in those decision-making processes, the possibility to be divergent exists by creating choices for how to accomplish final touches before the final choice is made.

Design Feedback

Through course structures, assessments, and feedback, design instructors play a significant role in students’ design process choices (Dannels & Martin, 2008; Tolbert & Daly, 2013) and their eventual professional practices. Feedback is an explicit way for instructors to direct students in their design processes (King, Young, & Behnke, 2000; Kluger & DeNisi, 1996; Littlejohn, 1992). Feedback in design guides students’ design decisions and facilitates the development of their design knowledge and skills. Research on feedback indicates a number of factors that influence the value that students gain from feedback, both in terms of impacting the project and overall student learning, including the amount of feedback, direction of attention (whether the attention was on the task or on the self), and timing of feedback (Annett, 1969; Balzer, Doherty, & O’Connor, 1989; Book, 1985; Jurma & Froelich, 1984; King & Behnke, 1999; King et al., 2000; Kluger & DeNisi, 1996).

Instructors have multiple roles as mentors, mediators, and managers (Marin, Armstrong, & Kays, 1999; Stanfill, Mohsin, Crisalle, Tufekci, & Crane, 2010; Taylor, Magleby, Todd, & Parkinson, 2001). As mentors, instructors ensure students achieve course learning goals and project goals. Pembridge (2011) distinguished mentoring for career development as preparing and promoting students through exposure and visibility, coaching, protection and offering challenging assignments within the organization from mentoring for psychosocial development as targeting the students’ sense of community, identity, and effectiveness in their role. Design interventions can provide both types of mentor-

Figure 1. Design process models (Cross, 1994; Moore, 2009).
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ship, supporting students' design knowledge and skill development and facilitating their identity as design practitioners through engagement in design practices. Dannels and Martin (2008) classified design feedback in a typology, which we used as a way to focus on different feedback types in our analysis of instructor feedback suggesting convergent and divergent design thinking.

Methods

We investigated if feedback provided direction regarding convergent or divergent design activity. Our work was guided by the following research question: "How does instructor feedback direct students to engage in convergent or divergent design thinking as they develop their design ideas?"

Participants and the Settings

Feedback sessions in dance choreography (CH), industrial design (ID), and mechanical engineering (ME) were chosen from a larger dataset provided by the Design Thinking Research Symposia (DTRS) organizers (Adams & Siddiqui, 2013) to provide a diverse set of data for analysis. Other DTRS scholars used the same datasets (Adams, Forin, Chua, & Radcliffe, 2014; Mann & Tekmen-Arach, 2014; Purzer, Fila, & Dick, 2014), but had different research goals.

Participants in CH included two students working individually on dance compositions and five dance instructors, in ID, seven students, one instructor, and an external client, and in ME, fourteen students on three teams and one instructor. The project duration varied: CH, 4 months; ID, 2 months; and ME, 4.5 months.

Dance choreography dataset

CH students worked independently to design dance pieces for a public performance. They chose the concepts for their pieces, developed the movement vocabulary, and assembled it into a final dance composition through multiple iterations. They also selected their performers and managed sound, lighting, and costume design. They directed two rehearsals per week, and presented their works-in-progress at three separate company showings. After these showings, five dance instructors provided feedback on the dance works in review sessions. In the first review, instructors provided feedback on initial composition ideas, which also included an initial selection of music and costume, and the concepts guiding students’ compositions. In the second review, the instructors responded to the synthesis of the dance elements into full works and how the costume and music selections aligned with the intentions and execution of the works. In the final review, instructors provided input on the revised full dance works. All three of the review sessions for the two students participating were included in the analysis.
Industrial Design Dataset

ID students worked on a project brief assigned by an office furniture company. The brief asked the students to focus on bringing excitement into the office environment through impromptu seating units treating them as accessories with color and emphasizing unique forms. Students were provided with particular design specifications, including shape, height, and size restrictions. It was important that the students' designs met the BIFMA testing criteria, which dictates a weight capacity of 253 pounds. Students participated in five reviews throughout the project. In the first review, students were asked to decide on five promising concepts at a desk critique. In the second review, students were asked to choose three solutions to present to the client. In the client review, students presented their concepts to the client and the instructor in front of their classmates. In the fourth review, the instructor evaluated full-scale prototypes, and in the final review, students presented both their appearance models and digital presentations of their solutions.

Mechanical Engineering Dataset

Three different mechanical engineering design tasks were provided to three engineering teams. The projects included designing: 1) an aquatic robot that can swim and move like a fish in order to follow real fish in the oceans and study them in their natural habitat, 2) a device that would safely open jars containing hazardous materials, and 3) a lever that tows aircraft out to a runway. Funding was provided for prototyping if the students got their budget plans approved by their instructor. Three reviews took place with an additional debrief in the form of a presentation to the entire class. The preliminary review, where initial ideas were presented, was not included in the dataset. Our analysis started with the second review, which focused on reviewing prototypes and early evaluation findings. In the third (final) design review, students demonstrated their final designs and prototypes to the instructor and were immediately graded.

Data Analysis

Our analysis began with open inductive coding, and then moved to categorizing feedback using Dannels and Martin’s (2008) typology. The final categories that emerged from our analysis were similar in nature to those of Dannels and Martin; some we renamed based on our initial inductive coding, and a few others were added or combined (Yilmaz & Daly, 2014). We then analyzed within each feedback type for evidence of instructor direction for convergence or divergence in students' idea development processes. We defined feedback as pushing toward divergent thinking if students were being encouraged to create alternatives. Feedback facilitating convergent thinking was defined as pushing students to make specific design decisions. There was also feedback that was neither convergent nor divergent, such as asking students to develop their ideas but not explicitly suggesting how that development should take place; that is, whether students should create some options to consider and then decide, or decide one way to achieve a particular goal and add it to the artifact.
Finding

In the following section, we present examples of various types of feedback to demonstrate explicit suggestions toward convergent or divergent thinking as well as to demonstrate ways instructors left it open to the students to determine how to address the issue raised (i.e., through convergent and/or divergent thinking).

Feedback Directing Convergence

Instructor feedback that suggested to students that they should engage in convergent design thinking to improve their ideas took different forms, such as asking students to specify design details, evaluate a variety of concepts, assess the project timeline and expectations, and analyze risk.

Instructors asking for students to specify details of the artifact was prevalent in the feedback sessions. These questions often explicitly directed students to engage in convergent thinking by clearly articulating a choice and the reasoning for a decision. For example, a CH instructor provided feedback that would require the student designer to clarify a movement vocabulary choice of their design: “I don’t know if that was on purpose . . . I’m assuming your intention was the . . . scan.” In the ID data, both the clients and the instructor asked students to be more specific in their concept ideas and the details of those concepts. For example: “The piece that comes out, what did you envision the material was?” The ME instructor often used specification questions either to understand the concept in detail or push the students to be aware of their decisions during the presentations. This was predominant in the engineering data, where students would present their concepts formally to the class and the instructor would ask for clarity to make sure he understood the details of students’ concepts. For example: “How is that tail attached to the white—the white bar—the ABS?” and “Why do we do 90 degrees one way? Why, why are we doing that?”

Feedback directing convergence included directing students to narrow down their solution concepts. This type of feedback was evident only in the ID data. This might be because this was the only situation where students maintained very different ideas as options for pursuit in the feedback sessions, whereas in ME and CH, the students were developing one main idea. This feedback pushed toward convergent thinking because the objective was to choose the concept(s) to pursue based on a set of criteria. When the ID instructor provided this kind of feedback, he sometimes stated his preference for which idea to pursue, but in other cases he asked the student designers to evaluate for themselves: “Rate these in order of your preferences,” and “Which would you rather develop? See this one is—this one is pretty far along. You gotta look at your materials.”

Instructors sometimes suggested that students test one or multiple design options by prototyping and testing or conducting choreography experiments in order to see how the concept would function. This feedback facilitated students’ decision making by using data from testing to determine the best option. For example, a CH instructor suggested prototyping a choreography idea through the use of a model: “You might do like flock of
bird exercises.” The CH instructors suggested exercises that would give the choreographers a feel for what the compositional choice would look like in the context of the piece as a whole or what kinds of emotions they would convey to the audience. In choreography, any consideration of ideas usually involves prototyping to some extent since choreographers will likely try it out on their dancers to see how something looks. The language of prototyping was not used in the dance data, but the idea is central to the way design happens in this field. The ID instructor also suggested testing to narrow down ideas: “The foam models are gonna tell you a lot, but I would—yours are simple geometry, and looking at quarter scale. This exercise is getting your ergonomics correct.” He also asked the students to assess the ergonomics and usability of the concepts using full-scale prototypes. The ME instructor did not ask students to prototype during the feedback sessions; however, in the transcripts, we observed the students referring to their prototypes, indicating this was a part of their expected design work. The instructor did not indicate revisions or a need to go back to the prototypes during the data segments analyzed for this analysis. Convergent thinking was promoted by having students test and validate ideas through prototyping and use the outcomes to make decisions about design details.

Instructors also provided feedback that aimed to keep students on track regarding the schedule and expectations of the project. Most of this feedback related to evaluating students’ progress directed convergent thinking because it pushed students to focus on the end goal and finish their design artifacts. For example, a dance instructor reminded a student, “You have to be done before Thanksgiving!” and the industrial design instructor similarly said, “We have a limited amount of time. All right?” Time management was especially prevalent in the ME instructor’s feedback due to the necessity of solutions’ feasibility at the end of the semester (this was also reported in Lande & Oplinger [2014]). He continually provided feedback to keep students on pace and reminded the class of the importance of the schedule: “Why were we trying to get ‘em last night as opposed to in the last three months?” Reminding students of time and pushing for students to meet deadlines would prompt students to make decisions about what concepts to pursue and to finalize details of those concepts, both of which are convergent thinking processes.

The ID instructor sometimes gave feedback that directed students to evaluate risks of their design options, and encouraged students to make decisions to avoid these risks. It pushed for a commitment to ideas that could work and would be done on time. It prompted convergent thinking because the instructor seemed to be trying to protect students from failure (not getting the project done on time, the outcome not working properly, poor form, etc.). The instructor wanted students to evaluate the risks of all of their ideas as well as the subcomponents of those ideas, and encouraged students to minimize these risks. For example: “Cause you wanna do something kinda safe” and “We want to be able to get the biggest bang for the buck. And this is going to sell to more people and this is going to appeal to more people because it, it’s got, it’s got the different looks, but it’s a simple form.”

Convergent thinking is critical in design success, and instructors pushed students in this direction using many forms of feedback by asking for more specific design details,
justifications for design decisions, prioritizations of concepts, clarifications of the evidence for decisions, and assessments of the project timeline and potential risks.

Feedback Directing Divergence

Throughout the design reviews, instructors provided feedback to direct the students towards exploration of diverse solutions or alternatives.

Both in the CH and ID feedback sessions, instructor feedback suggested that students consider multiple ways of achieving a particular goal of the artifact. The instructors suggested that students “play around” with ideas. For example, in the CH data: “So it’s important but to . . . play around with that. [W]hat are they . . . feeling when they do that? Is it like some kind of thing they just do or is it—-are they having a secret whatever your story is,” and “Play around with different hands, um, so what is it to you?” In the ID data, the instructor was discussing the form of the seating unit with the student and suggested modifying form to where it’s upholstered: “Maybe you—-what you do is you play—work backwards—from this.” Divergent thinking was emphasized as the instructor told students they should consider possibilities that they could consider before making choices about how to achieve their goals.

Another approach to encouraging students to explore was evident in the ID feedback sessions, where the instructor suggested that students look at how others have accomplished similar designs and get inspirations from them. For example, the ID instructor suggested students analyze the existing furniture to explore how “fun” could be integrated into designs: “But it needs to be, it, it, it has a great opportunity to be fun. That’s why look at the Herman Miller and it, it’s extreme, but I, I think with what true doing, like you could get some inspiration from it.” When he encouraged this type of exploration, the implication was that students should consider multiple ways of accomplishing that particular goal and look externally to create alternatives. For example, “You gotta get online, look at how people are sitting in those things,” and “This is a book of—you may wanna look at a purchase later. It’s like these are well-known designers who come up with something really unique and innovative, and . . . this just shows how they figured out how to make it, make it work in other words, how to build them.”

As a way to encourage students to explore multiple options, both the CH and ID instructors sometimes provided suggestions for what the multiple options to consider might be. For example, a CH instructor suggested: “I would play with timing or direction or placement of the stage space or other ways to, uh, surprise us.” The ID instructor suggested: “You could even maybe, maybe this inner—the inner piece could be out of, ah done out of a different material. Who knows? Maybe that since it’s small, and maybe it could be a bent plywood or something. I don’t know—what I like about this is you could change it out to different—potentially, to other materials and different combinations of materials.” Divergent thinking was encouraged as instructors gave students multiple ideas about where to start, and also modeled what different options could be by providing examples of the types of diverse ideas students could explore.
Instructors used feedback to direct divergent thinking to encourage students to explore new aspects of solution spaces. This was achieved by suggesting students discover multiple ways of achieving the same goal, asking students to use existing products as jumping off points, and modeling alternative options.

Neutral Feedback (Not Directing Convergence or Divergence)

While feedback existed that encouraged both convergent and divergent design thinking, we also observed feedback that allowed students to decide their own directions.

During feedback sessions, instructors often prompted students to add more detail to where decisions were not yet made. The instructors asked questions on aspects to include or eliminate, material choice, dimensions, mechanics, the relationship of components to one another, manufacturing techniques, how the product/performanc would be assembled or disassembled, force calculations, form modifications, CAD modeling, and cost. For example, the CH instructor identified aspects of on movement vocabulary, space, timing, and the relationship among performers: “I think you want to take each of your ideas, you know your panic, your sleep, and the caution and find out what the essence of each of those are you know like movement-wise and texture-wise, how to use time and space and all those cool things that you’re already doing very well and you can maybe articulate your idea more that way by thinking about those elements, the essence of each of those ideas and then we’ll see more you know distinguishing characteristics of that.” The ID instructor often focused on asking students to elaborate on the material choice and product dimensions, for example: “Now this might be hard for them to manufacture—you have to think about that.” The ME instructor focused on students making sure the idea would function and encouraged students to be specific on aspects of their designs: “Looking at that servo again . . . You might check that . . . with the relative position, and I realize the picture might not be accurate . . . But it looks like in an extreme location, I don’t think it’s going to work, but just check it to make sure.”

Instructors often pointed out design aspects to students where they needed to make decisions. This happened through questioning, for example, “Tell me about the materials. What are you thinking about on this?” and pointing out gaps in ideas, for example, “I didn’t understand her kind of a push—it was right before the two groups, lined up.” This request to elaborate indicated that students needed to make a choice, which could be done through thinking of one way to do it (convergent thinking) or multiple ways to do it and then making the decision (divergent and convergent thinking).

Instructors sometimes provided direct recommendations about how to make improvements to their design artifact. For example, in the CH data: “Is there any way that her foot could pop out over a person’s shoulder up here? In the ID data: “You may want to at that front lower point maybe a bigger radius on that. Right at the bottom.” In the ME data: “You might want to think about moving the pivot point to the center of pressure so that moment arm is reduced.” In these cases, instructors directed students to make changes to specific aspects of their ideas, and at times, suggested an option to consider.
in making the change. Examples like these seemed neutral as students could explore how to improve the design as suggested by the instructor.

Instructors also imparted judgments as a way to give feedback on aspects of the design concepts students needed to address, indicating what they liked and did not like about the artifact and what they thought was working and not working. The majority of the dance data focused on this type of feedback telling students the aspects of their choreography that were effective and ones that needed refinement. For example: “I liked how just the duet went back and [she] stayed out there by herself, that surprised me.” Also, “The one part of the whole piece that didn’t fit for me was the foot, when the foot came out. It was funny to me, and it didn’t fit with the rest of the piece for me, it didn’t make sense.” In the ID data, “This is really fascinating, too, ‘cause, again, it becomes a, a design element on its own, a, when you’re not using it” and “These actually may not be too stable.” In the ME feedback session, the instructor also practiced this behavior, focusing on whether the artifact would function as it should based on students’ design decisions. For example, the instructor said, “I got two concerns. One is the water tightness of the, ah, PVC. I think you need to make sure you got O-ring seals because you’re gonna have to go in and out of that a number of times. . . . And so using RTV or, ah, silicone. Ah, it won’t be too, ah, efficient for you if you have to pull it off . . . and then go in there and then reseal it and wait for it to dry and then pull it off.” This type of feedback did not seem to promote divergent or convergent thinking, but pointed out things that students should maintain in their design artifacts or change because the instructor did not think they worked.

Emphasizing aspects that students needed to further consider as well as reacting to decision quality were prominent types of feedback that seemed to be neutral in direction. The instructors’ goals did not seem to be to lead the student down a particular path, but rather let students take the lead and come to conclusions.

Discussion and Implications

Our analysis yielded examples of feedback that directed students to converge, diverge and did not push students in either direction, leaving it up to students to determine their own paths. While there were some distinctions in feedback culture, also evidenced in the work by Lande and Oplinger (2014) and Goldschmidt et al. (2014), there were many similarities in the ways instructors guided students’ design decision making.

During feedback sessions, instructors often encouraged students to specify details, make decisions, and stay on track with the course timeline, activities requiring convergent thinking. There was also evidence of feedback prompting divergent thinking. This came in the form of suggestions to explore ways they could accomplish an idea or suggesting multiple options for students to consider. We also identified feedback that seemed to allow students to take either a convergent or divergent approach moving forward. Adams et al. (2014) called this strategy “let the student figure it out,” which involved instructors encouraging students to make their own decisions. This type of neutral feedback was fairly common across the design instructors in our data set. It seems that
in some cases instructors were trying to point out areas that needed to be addressed, but did not push students in terms of how (convergently or divergently) to address them.

Overall, feedback recommending convergence was more prominent than feedback recommending divergence, especially in the ME dataset. Rather than pushing students to investigate further possibilities for alternative solutions, instructors more often advised students to make choices. Convergent thinking is essential for design success; however, one important question that emerged from our work is when there is room to pursue a risky idea. Instructors did not tend to encourage students to abandon ideas or to go back to the drawing board and think of several different ways they could do something. In many instances, realizing ideas was prioritized over searching deeper for “better” solutions to the same design problems. Additionally, we did not find any general feedback in which instructors asked students if they had fully explored their options, either for their overall concept or components of their ideas. Instructors highlighted places where students needed to make decisions, but did not ask if students had given themselves enough options among which to decide.

Having students choose when to be convergent or divergent is important as it models real design practice; however, it could make it more likely for students to engage in convergence because the overall design process is convergent. In general, divergence is less prominent as design processes move toward completion; however, we posit that there is value in identifying places for divergence in later design phases and recommending to students that they engage in this type of thinking. This feedback in design education can support students in becoming practitioners that can successfully converge and diverge throughout their design work.

Implications

Several implications for research and pedagogy emerged from our work that focus on the role of divergent design thinking throughout design processes and how, within the scope and timeline of design courses, instructors can facilitate students’ engagement in cycles of convergence and divergence.

One research implication is that design researchers can explore students’ actual decisions based on feedback provided and whether the feedback had been applied as it was intended (convergently or divergently) by the instructor. Since the ultimate goal of design is to specify one artifact, students could be more likely to favor convergent activity when instructors leave decision making to the students. A related pedagogical implication is that design instructors provide feedback that helps students take appropriate divergent pathways throughout their design work. Design processes are overall convergent; however, instructors can help students diverge throughout design processes at appropriate exploration levels. For example, an instructor could say, “What are the other ways for the user to interact?” (broad exploration) or “What are five different materials you could consider here?” (narrower exploration). Instructors can demonstrate these areas where students have choices and should not default to one option before considering multiple ones.
Additionally, while divergence is fundamental to early design stages, it can have an important role in mid to later phases; the amount of divergence likely changes but there are benefits to later design phase explorations. Banathy's (1996) design process model illustrated such an iterative process where the design process was described as repeated steps of divergence and convergence, and analysis and synthesis. The same iterations throughout the entire design process were characterized by Cross (1994) as divergent and convergent cycles. Cardella et al. (2014) emphasized the importance of both reducing and maintaining ambiguity throughout design work, which is consistent with the necessity for convergent thinking to bring clarity to an idea and determine details as well as the necessity for divergent thinking to generate multiple options for consideration. These suggest that instructors can provide feedback that helps students see how divergence fits throughout design processes.

Our analysis revealed that some of the convergent feedback directed students to minimize risk of failure in their design decisions. It is important for students to have design successes; however, one question that emerged from this finding is when do instructors encourage students to take risks. In our data, there were not occasions where instructors pushed students to think more divergently into “unsafe” territories. Divergence is not equivalent to risk-taking nor does it lead to design failure, but divergent thinking promotes exploring unchartered idea territories, which takes time and has risks associated with it. An implication for researchers is to explore if and how risk is supported or hindered in various design course structures, and the connection of risk to divergent and convergent feedback by instructors and pathways taken by students. An implication for instructors is to determine when and how in their design curricula students can have the opportunity to take risks, facilitate successful divergent thinking so that students can generate more radically innovative solutions, and allow students the opportunity to pursue these ideas in their design work, even if they are ultimately unsuccessful.

Finally, course goals and structures were likely connected to the feedback given, that is, instructors provided feedback to maintain alignment between students’ design work and their goals for the course. An implication for researchers is to explore divergence and convergence in successful design processes of experts. A related instructional implication is to reconsider course goals to allow for cycles of divergence and convergence throughout. As time is often a limitation, educational programs can provide various opportunities where the focus of the courses shifts. For example, one design course could focus more on the design “front end,” holding students less accountable for a working prototype and more accountable for executing divergent and convergent strategies for defining and refining a design problem, generating and prototyping multiple ideas, and developing engineering requirements for a final design outcome, without actually building and assessing the final artifact.
Conclusions

Our analyses revealed examples of feedback across three different design disciplines representing pushes toward both divergent and convergent thinking as well as neutral feedback that allowed students to decide their design paths. This exploratory study helps us, as instructors, to be more reflective and purposeful about the feedback we give, and how that feedback could support or hinder innovative ideation pathways. The resulting insights from these analyses enable the design education community to better understand how to engage students in divergent and convergent design thinking throughout design processes, as the both types of thinking are critical in idea development and successful design outcomes.

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