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Use of Skill Acquisition Theory to Understand Novice to Expert Development in Design Ethnography*

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The design processes engineers use to develop artifacts have a significant effect on the utility and impact these artifacts have on society. Traditional design processes are technology-centric, focusing on the artifact being developed with less emphasis on the context, culture, and people for whom they are developed. Human-centered design processes, however, strive to place the humans who will interact with the artifact at the center of the design process. These processes require a deep understanding of the stakeholders and a product's context of use. One method for obtaining this deep level of understanding is design ethnography, a set of methods derived from research methods developed within social science and used to understand participants preferences and context of use. To date, the limited research on design ethnography education has demonstrated that there is a significant gap between what novices can produce in their use of design ethnography and what is reported in the literature on the use of design ethnography within industry. In this paper we interpret the findings of design ethnography studies (of both novices and experts) through the lens of the Dreyfus and Dreyfus model of skill acquisition. We demonstrate how this theory of skill acquisition explains specific results found in the literature and the challenge of developing design ethnography as a skill. We also discuss the pedagogical implications of this model of design ethnography learning and consider Kolb's theory of learning as it applies to the development of students as design ethnographers.

Keywords: design ethnography; design expertise; design education

1. Introduction

Design ethnography evolved from the ethnographic techniques developed by anthropologists; during design, it allows one to gain a deep understanding of the stakeholders who will ultimately interact with a product and the environment where it will be used [1–3]. Design ethnography includes a host of data collection and analysis methods that lead to findings that inform design decisions. Data collection methods include observing stakeholders while they interact with products of interest or perform daily activities; interviewing stakeholders about their priorities, experiences, and preferences; observing a product's environment; developing genealogies and social maps; performing in-situ usability testing; photographing, videotaping and documenting; researching archives; and "deep hanging out" [4–7]. Data analysis methods include inductive and deductive coding, the constant comparison method, and thematic identification [8, 9]. Design ethnography has been studied most during needs identification and requirements elicitation [10–13], but has also been shown to increase creativity during concept generation [14], which can lead to improved product success [15]. However, studies have shown that design ethnography is challenging for students and novices to implement due to the complexity involved during data collection, analysis, and application and that these designers require more extensive support as they develop design ethnography skills [16–18].

Application of design ethnography to engineering design is a complex cognitive skill requiring significant information processing [19]. Design ethnography requires individuals to complete a full information processing cycle, identify a specific information need, determine appropriate information sources, gather and synthesize information, and then analyze this information in order to inform design decisions [20, 21]. Previous research has demonstrated that students struggle with aspects of information processing, such as assessing information quality and defining the information problem [22, 23]. During implementation of design ethnography, information processing tasks are complicated by many factors. For example, information needs may only be vaguely defined (e.g., during needs identification or requirements development) requiring design ethnographers to find information related to a problem that they cannot articulate clearly. Gathering information through

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design ethnography also requires the use of skill sets that may be underdeveloped in many engineering designers; design ethnography methods such as observations and interviews are used extensively by social science researchers, but engineering designers are rarely exposed to these methods during their academic training.

Research on the use of design ethnography has demonstrated the benefits of using these methods during design to ensure that stakeholders' wants and needs are fully considered and that the context is deeply understood. These benefits, however, are mitigated by the barriers to implementation that use of design ethnography presents and which are observed when novices attempt to implement these methods. This suggests that in order to introduce engineering design students to design ethnography effectively, evidence-based pedagogy should be developed. In this paper, we present research findings on design ethnography use by designers across the expertise continuum from novices to expert design practitioners through the lens of the Dreyfus and Dreyfus model of skill acquisition [24]. This model situates and organizes existing literature and guides pedagogical development needs.

2. Theoretical framework

The Dreyfus and Dreyfus model of skill acquisition was developed through empirical studies of aircraft pilots and their training programs [25–29] and later applied by other scholars to a variety of fields including medical education [30–32], computer programming [33], ethics [34], sports [35, 36], and engineering [37]. The model represents how skill development is embedded in the context in which an individual solves a problem [38, 39]. The model consists of five stages (novice, advanced beginner, competent, proficient, and expert) whereby a student's level of sophistication increases with each stage of development. Below we detail each level of the model as described by Stuart Dreyfus in an updated description of the model [40].

Novice: Novices begin by learning context-free rules that can be applied without required skill or prior experience. Dreyfus describes a novice student driver being told to shift into 2nd gear when the speedometer needle reaches 10 mph. The novice driver uses this rule without regard to potentially relevant situational information. Therefore, when applied to real world situations, success is not guaranteed because situational factors typically disrupt the use of these simple rules (e.g., the car is on a hill). At this level, an individual does not modify these rules to adapt to a situation.

Advanced Beginner: At this level, a learner begins to recognize situational cues that must also be considered in addition to context-free rules. For example, a student driver using the engine sounds to determine when to shift. Learning to identify similar contexts, the advanced beginner recognizes when to apply a rule from another context and how to develop heuristics that allow the generation of abstract concepts based on previous experience. He/she begins to develop heuristics that allow for abstract concepts to be generated from concrete prior experiences.

Competent: At this level, an individual recognizes the complexity involved in the problems he/she is solving and appreciates that context-free rules cannot be blindly applied. The individual becomes emotionally invested in the outcome (e.g., success or failure) and, therefore, it is more challenging to apply the detached context-free rules given to a novice/advanced beginner. Individuals recognize that the vast amount of potentially relevant information in a given context requires prioritizing information during the decision making process.

Proficient: At this level, the learner relies less on context-free rules, instead transitioning to personal experience. Successes and failures now become the main learning tool as a proficient individual is seeking to increase their experience level to better prepare to tackle diverse and new situations. A proficient individual can use intuition to understand a situation, but continues to rely on analysis to make decisions.

Expert: At this performance level, an individual can discriminate between subtle situational differences and can intuitively make decisions. Experts intuitively understand situations and how to achieve goals. Evidence of this can be seen in expert chess players whose ability to assess and respond to situations does not degrade with increased rate of play or the addition of other cognitively demanding tasks, indicating that they are not relying only on analytical decision making [40]. Experts approach problem solving in a more open-ended and intuitive manner.

The model refers to four mental functions within each level of expertise: components, perspective, decision, and commitment [26, 40]. Components are the contextual elements of a problem or situation that an individual can perceive (i.e., can she/he only perceive context-free elements or can he/she also identify important contextual elements). Perspective refers to an individual's ability to select the most important aspects of a situation or problem. Decisions can be made in one of two ways: analytically or intuitively. Finally, an individual's commitment refers to whether or not (and in what way) an individual feels personally responsible when understanding a situation, making a decision, and the subsequent outcome. Table 1 displays a

Table 1. Characteristics of each level of the Dreyfus and Dreyfus model of skill acquisition, from Carraccio et al. [30]

Novice	Is rule driven. Uses analytic reasoning and rules to link cause and effect. Has little ability to filter or prioritize information, so synthesis is difficult at best and the big picture is elusive.
Advanced beginner	Is able to sort through rules and information to decide what is relevant on the basis of past experience. Uses both analytic reasoning and pattern recognition to solve problems. Is able to abstract from concrete and specific information to more general aspects of a problem.
Competent	Emotional buy-in allows the learner to feel an appropriate level of responsibility. More expansive experience tips the balance in reasoning from methodical and analytic to more readily identifiable pattern recognition. Sees the big picture. Complex or uncommon problems still require reliance on analytic reasoning.
Proficient	Breadth of past experience allows one to rely on pattern recognition such that problem solving seems intuitive. Still needs to fall back to methodical and analytic reasoning for managing problems because exhaustive number of permutations and responses have provided less experience on particular problems. Is comfortable with evolving situations; able to extrapolate from a known situation to an unknown situation. Can live with ambiguity.
Expert	Thought, feeling and action align with intuitive problem recognition and intuitive situational responses to problems. Is open to notice the unexpected. Is clever.

summary of the Dreyfus and Dreyfus model, from Carraccio et al., where it was applied to the development of clinical skills in medicine [30].

3. Design ethnography and the Dreyfus and Dreyfus model of skill acquisition

This section reviews the literature on design ethnography practice and education through the lens of the Dreyfus and Dreyfus model of skill acquisition and provides an illustrative example for various levels of expertise [41]. While the Dreyfus and Dreyfus model is divided into five levels of skill acquisition, we condensed the levels of novice with advanced beginner and proficient with expert to represent three levels of skill development. This reduction is due to the limited literature in the area of design ethnography, preventing the necessary detail to establish five levels of skill acquisition. The descriptions of each of the three levels include results from our prior work and the larger literature, and also include an example developed from our experiences working with students as they develop expertise.

3.1 Novice to advanced beginner levels

A novice or advanced beginner design ethnographer focuses on the application of context-free rules, struggles with ambiguity, and is unable to identify the important focus areas in a complex situation. Context-free rules in design ethnography include: sample a diverse set of stakeholders and environments, ask open-ended questions, perform data analysis during and after data collection, verify conclusions drawn from design ethnography through stakeholder feedback, inductively develop conclusions, and identify data saturation to determine when data collection should be concluded (among many others) [1, 42, 43]. The use of context-free rules within the social science literature has been highlighted as a foundational step to performing traditional ethnographies but also acknowledges that these context-free rules should be adapted to the ethnographer's particular domain of study [44, 45]. Another characteristic of novices is that they struggle to overcome the ambiguity associated with design ethnography use. Design ethnography, and qualitative research methods in general, require one to gather data and navigate inconsistencies and ambiguities [9]. It is the task of the design ethnographer to consider all the data in order to identify patterns that could lead to relevant findings. One source of ambiguity within design ethnography implementation is determining who the appropriate stakeholders are as they may not be clearly defined or a combination of stakeholders might be required to fully understand a given problem context. Novices and beginners also lack perspective; they cannot yet identify the important focus areas within a complex situation [46]. This is a critical aspect of design ethnography as the amount of information being collected during data collection can easily become overwhelming if the designer does not have the ability to filter out inconsequential information.

To illustrate how a novice to advanced beginner might use design ethnography techniques we consider the example of a novice design ethnographer conducting an interview in order to develop require-

ments and specifications for a product. During the interview, the novice design ethnographer will focus on the use of context-free rules to develop questions. For example, he/she might exclusively use open-ended questions even when a close-ended question might be more appropriate. A novice design ethnographer will struggle to identify the most relevant information provided by the stakeholder and this may cause challenges when the novice attempts to generate relevant follow-up questions. The novice will additionally struggle with the ambiguity generated by interviewing multiple stakeholders who often have differing opinions on a single topic. The novice will struggle to synthesize information from multiple stakeholders if the information gathered is not in agreement.

Through studies of novice design teams, we have observed the behaviors described above when novices employ design ethnography. A study of capstone design teams exemplified novices' reliance on the use of context-free rules whilst using design ethnography and their struggles to deviate from these rules when contextual details demanded an adapted strategy [4, 18]. Our research outcomes have also demonstrated novices' struggles with ambiguity and difficulties when attempting to synthesize and analyze ambiguous data collected during design ethnography [18,47]. Other studies have investigated novices' difficulties determining important focus areas when performing design ethnographies. One study found that students struggled to differentiate between design relevant information obtained during observations and cultural differences that students noticed as a result of performing observations in a clinical context in a low-income country [48]. Novices similarly discussed challenges associated with the immense amount information that is associated with performing design ethnography and how they find it difficult to determine what is the most important information to focus on, particularly when collecting and analyzing data [18].

3.2 Competent level

When a learner reaches the competent level of skill acquisition, their approaches and behaviors become more refined, enabling them to understand the complexity of a given situation, develop appropriate strategies, and refine their focus. Understanding the complexity of a given situation and developing appropriate strategies for dealing with these complexities (e.g., not blindly applying context-free rules and knowing how to navigate some ambiguity) is a primary differentiator of a competent performer. He/she will begin to use his/her repertoire of previous experiences in order to inform decision making and better deal with novel situations that arise. The transition to becoming a competent performer involves the ability to discriminate between important and unimportant situational details associated with a given context. This is a critical transition stage since performing a thorough design ethnography requires designers to perform an assessment of the context of use for a product and its stakeholders in order to determine what aspects are most relevant to the design process.

In our example, the competent design ethnographer approaches stakeholder interviews with more experience and the ability to identify and adapt to contextual information. For example, the competent design ethnographer does not restrict him/herself to a pre-defined list of questions for an interview, but rather adapts the interview protocol based upon the expertise of the stakeholder and the answers provided by the stakeholder. These questions are not strictly guided by context-free rules (i.e., they are not strictly open-ended), but rather vary based upon the designer's previous experience. He/she is able to formulate follow-up questions that are relevant and important to the eventual design. The ability to identify important areas of focus by the competent design ethnographer is critical as he/she determines what the stakeholder's particular area of expertise is and adapt his/her line of questioning to better suit the particular stakeholder in question. Experience and the ability to adapt allow the competent design ethnographer to perform more effective interviews and gather deeper information from stakeholders (compared with more superficial interviews conducted by novices).

While our previous studies on students have largely elucidated the behaviors of novice design ethnographers, some students have demonstrated behaviors that align with the competent level of the Dreyfus and Dreyfus' model. For example, during a design task study investigating students' ability to use design ethnography during requirements development, we found that some students combined observations with interviews using the situational details to guide the questions they posed. This strategy allowed these particular students to perform more effective interviews with stakeholders, distinguishing themselves from the more novice behaviors of other students [49]. These students understood the rich contextual information available during observations and leveraged it to conduct more effective interviews with stakeholders. Previous studies of students using design ethnography have also elucidated the challenges novices face when attempting to improve their skill in using design ethnography. For example, in an academic setting, students face logistical hurdles to gaining experience and frequently lack enough time to effectively employ design ethnography [18, 47].

Another major hurdle to learning to perform design ethnography is the possible delayed recognition of the importance of certain information and/or stakeholders. For example, a design team might conduct interviews with stakeholders during the problem definition phase of the design process, but not realize that they did not ask the appropriate questions until later in the design process when the information is needed (e.g., engineering specifications development) making it increasingly difficult to learn from errors [18,47].

3.3 Proficient to expert level

Once an individual reaches the proficient level of skill acquisition, experience and intuition dominate the execution of a particular skill. Individuals rely on experience to determine which aspects of a situation or problem are most important to focus on, instead of relying only on context-free or general rules. Practitioners have argued that extensive experience with the qualitative methods of design ethnography is critical to successfully implementing the techniques within a design project, and that novices tend to ignore or circumvent important steps (particularly with respect to data analysis) [46, 50]. Intuition is a central feature of the expert level of skill acquisition. Individuals no longer rely on purely analytical reasoning to solve problems, but use personal experience to inform decision making. For example, during design ethnography interviews, one cannot pre-formulate every question that might lead to meaningful and design relevant responses; follow-up questions, based upon interviewee's responses, are critical to conducting successful interviews and must be generated on short notice and in a fluid manner [20]. The expert design ethnographer can draw from a large bank of effective follow-up questions, allowing him/her to perform a deep dive into a given topic and avoid acquiring superficial knowledge.

In our example, the proficient or expert design ethnographer would conduct a very different interview than the novice. The expert would develop an interview protocol that is tailored to the stakeholder being interviewed based upon earlier interviews (conducted with a variety of stakeholders) and/or observations of the stakeholder in their natural environment. During the interview, the expert would not hesitate to deviate from the interview protocol in order to pursue a line of questioning that the design ethnographer believes would generate beneficial information for the design process. The design ethnographer would rely largely on his/her prior experience and intuition to determine what the most important line of questioning is and pursue questions that would result in a deep understanding of both the stakeholder and the context of use for the eventual product. The expert also has a strong understanding of how information will be used during subsequent phases of the design process based on substantial previous experience, and can generate more appropriate follow-on questions to elicit the relevant information in a single interaction.

Intuition and experience are central features of the expert level of skill acquisition. Individuals no longer rely on purely analytical reasoning to solve problems, but use personal experience to inform decision making. Within design ethnography, this is exemplified by the need to generate relevant follow-up questions, based upon interviewee's responses, quickly and potentially without prior knowledge of the topic [20]. Design ethnography literature emphasizes that successful design ethnographers must build a repertoire of experiences in both data collection and analysis to become experts [46].

4. Pedagogical implications

While a four-year curriculum may not allow for students to develop proficient or expert levels of design ethnography skills, prior studies have shown that a broad range of skills in design ethnography implementation exists among students. In a study of students' use of observations and stakeholder interviews (key components of design ethnography) some students demonstrated more advanced interviewing and observational behavior (interacting with stakeholders as co-designers, rather than simply as customers) [49]. Pedagogy and tools need to support novice/advanced beginner design ethnographers during implementation to enable them to progress to higher skill levels, where the benefits of design ethnography for students would more closely match those discussed in the literature. Below, we draw on Kolb's theory of learning to describe how design ethnography pedagogy could be constructed to support students' deeper learning.

Kolb's theory of learning (Fig. 1) consists of four stages: (1) a learner has a concrete experience, (2) he/she then reflects upon this experience, (3) through reflection, the learner develops abstract concepts enabling him/her to generalize his/her experience, and (4) the learner applies these new abstract concepts to a new experience and begins the cycle again [51]. Kolb's theory of learning has been applied to a range of fields including nursing [52], political science education [53], higher education [54], and engineering laboratory education [55].

In typical engineering courses, students complete problem sets, reflect on each problem set when provided instuctor feedback, and then apply their learning to future problem sets or tests (enabling a

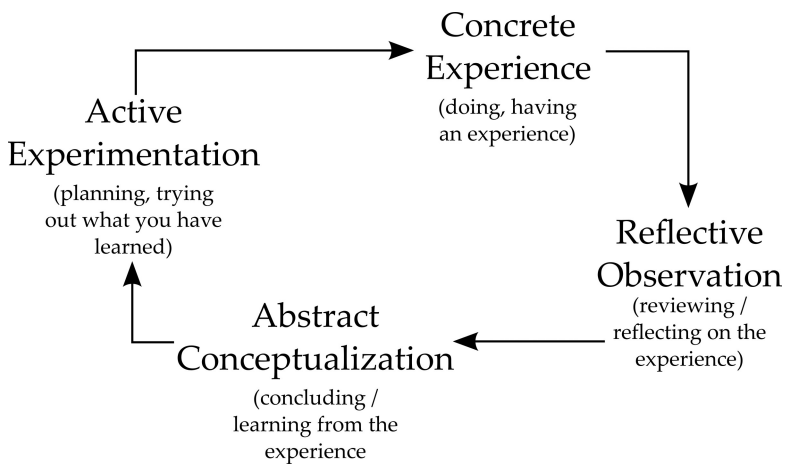

Fig. 1. Kolb's theory of learning.

full cycle as described by Kolb). In contrast, design ethnography is composed of an interwoven series of data collection, analysis, and application experiences. In some cases, data collection may precede application to a design decision by weeks or months. Reflecting upon a data collection experience prior to applying the data to a design decision means that the student does not have all the relevant information when developing abstract concepts through reflection. For example, during interviews with a capstone design team developing a surgical tool, the team described how they realized that a size specification obtained from a surgeon during early design phases was highly inaccurate. The team was only able to recognize this after 3D printing their concept solution several weeks after the interview with the surgeon. To adequately reflect upon the interview, the team would need to recall their interview with sufficient detail and assess what may have caused the inaccurate specification [18]. This large gap in time (between experience and reflection) significantly increases the challenge of performing Kolb's learning cycle in a meaningful way. Therefore, to appropriately implement Kolb's theory of learning in the context of design ethnography, instructors need to ensure that students perform multiple rounds of reflection throughout these extended concrete experiences (e.g., reflecting after collecting data, reflecting after each round of data analysis, and finally reflecting after the data is applied to a design decision).

Developing abstract conceptualizations based upon reflection is how an individual applies prior experience to new situations. During use of design ethnography (particularly during data collection) researchers are encouraged to sample diverse situations and stakeholders to obtain both breadth and depth of knowledge. Students may encounter challenges identifying how experiences within one context/stakeholder can be applied to the next context/stakeholder. Pedagogy must focus on helping students obtain abstract conceptualizations that are helpful during future experiences (i.e., are not overly specific to their most recent experience). For example, during reflection students might be required to develop a list of questions they should have asked a stakeholder (or specific observations they should have made); students could then apply these new questions to future interviews and observe the differences in the data they collect. We also believe that this should be enabled by formalizing the process of abstract conceptualization within design courses (e.g., students are required to reflect on experiences and write-up the abstract concepts that they believe are relevant to future use of design ethnography).

5. Conclusions

Design ethnography requires engineering students to employ methods not typically required in engineering coursework. Based on principles of qualitative research, design ethnography requires an extensive level of information processing to be performed in order to reach appropriate conclusions. Previous literature has demonstrated that students tend to struggle during implementation of design ethnography and do not typically obtain the benefits documented in studies of expert practitioners. By assessing the results of novice studies through the lens of the Dreyfus and Dreyfus model of skill acquisition, we have elucidated several potential reasons for this mismatch. We also identified the need to develop pedagogical tools and teaching methods that consider the particular challenges associated with teaching novice students how to use design ethnography.

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