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Expertise comparison among product design students: a cross-sectional analysis

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Abstract
Product design expertise has mostly been studied in relation to problem-solving and the act of designing. In this paper, we approach the topic from another perspective and explore the differences in product perception of students from different education levels. We conceptualize product perception as a representation of critical thinking towards designed objects and professional assessment/understanding of artifacts. Our aim is to evaluate how students' product perception change over the years of undergraduate product design education. Data was collected through students' written product evaluations of a ball-point pen. 41 first-year, 29 second-year, 33 third-year, and 26 fourth-year undergraduate product design students participated in the study. We analyzed students' product evaluations through initial and focused coding. Our findings indicate a shift from ordinary to professional sense-making between the second- and third-year students. There are three main points that define the professional sense-making of students: a dependence on subjectivity, the significance attributed to users, and better synthetic capabilities that are built around form, material, manufacturing, and detailing relationships.

Keywords Product perception · Critical thinking · Design expertise · Product design

Introduction

Expertise is a multi-faceted issue. Numerous scholars (e.g. Alexander, 2003; Collins & Evans, 2009; Dreyfus & Dreyfus, 1986; Tynjala, 1999) proposed different theories of expertise and models of expertise development. Similarly, a growing body of literature on design expertise (e.g. Cross, 2018; Lawson & Dorst, 2009) and product design expertise (e.g. Gray, 2019; Popovic, 2004) has emerged.

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Typically, studies regarding expertise in design have looked into problem-solving or the act of designing. They focus on defining design expertise in comparison to other professions with a focus on differences that result from training and experience (e.g. Bartram, 1982; Lawson, 1990). Or, they compare novices and expert designers to define the characteristics of professional design activity and features of design expertise (e.g. Ahmed et al., 2003; Cross et al., 1994). The data mostly come from protocol studies, interviews, and case studies that look into group/individual problem-solving activities (e.g. Kokotovich, 2008; Rowe, 1987), problem framing/structuring (e.g. Björklund, 2013; Gray, 2019), decision making (e.g. Akin & Lin, 1995), cognition (e.g. Kruger & Cross, 2006), and creativity (e.g. Cross et al., 1994; Lu, 2017).

However, there are other ways of analyzing design expertise beyond applying common models of expertise to design (Tan, 2021) and studying the act of designing. As the word design covers both a goal-oriented process and the consequences of this process (Friedman, 2003), another approach can be studying designers' evaluation of artifacts, namely the design outcome.

Product designers are expected to assess artifacts differently than non-designers (Blijlevens et al., 2009; Hsu et al., 2000). Product design is not only about the "visual expression" of products (Buchanan, 2001, p. 14). Rather, product designers approach artifacts as experiences and systems (Desmet & Hekkert, 2007) that have practical, aesthetic, and symbolic functions (Heufler, 2004). It follows that novice and expert designers should have different perspectives on existing design solutions.

In this paper, we analyze how product design students' product perception differs across different education levels (e.g. first-year vs. fourth-year students). Here, we conceptualize product perception as a representation of critical thinking towards designed objects and professional assessment/understanding of artifacts. We qualitatively analyzed 129 written product evaluations of students and provide a descriptive analysis of design students' product perception. Our findings provide three main insights for product design education. First, the differences between the first-year and fourth-year students illustrate the impact of product design education on expertise development. Second, the evaluation of design education based on students' product perception has the potential to highlight the pedagogical impact of design education that has been criticized for being skill- and competence-oriented (Findeli, 2001; Norman, 2010). Last, our results expand design expertise literature through defining professional sense-making with a dependency on subjectivity, the significance given to users, and better synthetic capabilities used for form, material, manufacturing, and detailing relationships.

Product design expertise and education

There has been a growing interest on expertise since the second half of twentieth century (Eyal, 2019). Over the years, scholars (e.g. Collins & Evans, 2009; Eyal, 2019) tried to systematize the conception of expertise in different ways. As expertise is associated with "knowing, acting and being" in a particular field, studies try to define domain-based features of expertise. In a similar fashion, in this paper, we focus on one such façade of expertise literature and discuss the development of product design expertise in reference to product perception through undergraduate product design education.

According to Eyal (2019, p. 25) "… we often speak of expertise in a *promissory* mode, not as something exists but as something that needs to be developed." Development of expertise is a continuous process starting with formal education and continuing throughout professional practice (Boshuizen et al., 2004). Green and Bonollo (2004) argue that it takes at least 10 years to develop such expertise in design. Through experience and learning, designers develop and integrate cognitive skills and domain knowledge (Lawson & Dorst, 2009). Since the design profession is often defined in relation to solving ill-defined problems (Buchanan, 1992; Cross, 1990, 2004), most of the studies on design expertise explored how designers use cognitive skills and domain knowledge in problem-solving process and design activity.

Scholars previously compared problem-solving process and design activity of designers vs. non-designers, and novice versus experts. The studies that investigated the similarities and the differences between novice and experts commonly compared less experienced design practitioners to more experienced ones (e.g. Wong et al., 2016), design students to design practitioners (e.g. Cila et al., 2014), and design students from different education levels (e.g. Casakin, 2011). Findings from these studies show differences between novice and experts in terms of skills, capabilities, and design ability (Dorst & Reymen, 2004). Novices utilize more commonsense knowledge, depend more frequently on trial and error, and apply less domain-specific strategies while solving design problems (Popovic, 2004). Their design solutions resemble existing design solutions more than experts' solutions (Yang et al., 2013). They take a depth-first approach (Cross, 2004). On the other hand, experts are more solution-oriented, start proposing design solutions much earlier in the process (Cross, 2004), and depend more on generative reasoning (Lloyd & Scott, 1994). Experts adopt breadth-first and top-down strategies (Cross, 2004). They possess reflective thinking abilities built on previous experiences and are more capable in understanding user needs (Lawson & Dorst, 2009). As they possess deeper experiential knowledge in the field, they can make better use of analogies (Casakin, 2010) and metaphors (Cila et al., 2014) to make judgements regarding the ill-defined design problems and their solutions.

While previous studies define the competencies and capabilities of novice and expert designers, "… there is still precious little real understanding of … how to help students move from one [novice] to the other [expert]" in the field of design (Cross, 2004, p. 249). Educators experiment with various strategies to teach product design so that the students become more competent practitioners. These strategies mostly focus on studio work and are built upon the understanding that product design can be best taught through learning by doing (Dorst & Reymen, 2004). As such, students are assigned projects in which they gradually engage in more complex design problems (Cross et al., 1994). Educators incorporate different design methods and tools such as user involvement methods (McDonagh et al., 2011) and sustainable practices (Firth et al., 2016) in projects as a means of communicating the various ways of handling design problems. Through design critiques in studios, students explore form-giving and product semantics. They learn how to develop an adequate product language for communicating the functionality and usability of artifacts to users (Redström, 2006).

This centrality of form-giving in design is criticized as well. The overemphasis on "doing" gives the impression that product design education is vocational training with a focus on solving problems through form-giving (Findeli, 2001; Krippendorff, 2006). The progression from novice to expert is perceived as being rather skill-oriented and product designers have been criticized for not having the knowledgebase needed to address contemporary design problems (Norman, 2010).

However, product design is about the "total product" (Buchanan, 2001, p. 14) together with its practical, aesthetic and symbolic functions (Heufler, 2004). As a profession, it aims to create pleasant user experiences (Desmet & Hekkert, 2007), address social, political, and sustainability problems (Manzini, 2019), and engage in ethical practices towards the development of more sustainable futures (Irwin, 2015). In order for students to develop domain-specific knowledge in relation to these issues, product design curricula include courses about marketing, human factors, intellectual property, and research methods. The aim is to help students develop "adoptive expertise" (Popovic, 2004) and to assist them as they become critical thinkers. Such a holistic approach to product design indicates the importance of defining design expertise beyond design process, design activity, and problem-solving. It is important to explore designers as critical thinkers who have a professional perspective on artifacts, the very outcome of the design act.

According to Krippendorf (1989, p. 14) "… forms designers create … result from nothing other than a professional, as opposed to ordinary, sense-making." As outcomes of this professional sense-making activity, designers are expected to have a deeper understanding of artifacts. Hsu et al. (2000) and Blijlevens et al. (2009) reported that designers engage with domain-specific evaluations, perceptions, and preferences in relation to artifacts. They "are more capable of detecting subtle differences in components' features and proportions" (Wang, 2020, p. 17) and are expected to identify a larger number of and more abstract product attributes (Blijlevens et al., 2009). Findings from Popovic's (2004, p. 542) study show that "Non-domain experts usually described problems at very concrete and specific levels. Contrary to this, domain experts used more abstract categories for description." Furthermore, designers and non-designers demonstrate differences in terms of their mental models pertaining to artifacts (Norman, 2002; Redström, 2006). These mental model differences were documented to cause frustrations for users as designers are not always successful in developing design solutions that are in line with non-designers' mental models. These differences partly result from professional expertise gained through experience (Krippendorff, 1989, 2006).

These previous studies indicate that designers' approach to artifacts is conceptually different from non-designers. However, we do not have enough knowledge on how these conceptual differences develop. Furthermore, to our best knowledge, there is no study that describes the differences between design students' product perception. We aimed to address this gap and structured this study to assess differences among first-, second-, third- and fourth-year product design students' product perception.

Methodology

We designed a cross-sectional study and analyzed the students' product perception assessed via product evaluations. Our data collection involved a simple paper-and-pencil technique. The undergraduate product design students were given a one-page (double-sided) data collection sheet and an object to evaluate.

The object was the ball-point pen depicted in Fig. 1. This object was selected from a list of options through discussions with three other product design educators. Our short list of object alternatives (i.e., Nestle plastic PETE water bottle, CocaCola soda can, 3M Scotch Magic tape dispenser, Mas Force scissors, Bic Round Stic ballpoint pen, Leva clothespins) included objects that matched two criteria. These criteria were defined based on the literature review. First, we sought out an everyday artifact that was not excessively complex.

Fig. 1 The pen that was distributed to students for evaluation

Research has shown that human cognition is driven by controlled and automatic modes of processing (Bargh & Chartrand, 1999; Bargh & Ferguson, 2000; Sloman, 1996). Either consciously or unconsciously, people evaluate a given stimuli based on their individual, social, and cultural milieus. However, objects that we repeatedly use in our daily life, are usually overlooked and taken for granted. They become anonymized objects isolated from their backgrounds, creators, and etc. For this reason, we aimed to select an object that is blended into users' everyday practice so that participants' judgement would not be influenced by the object's designers, history, and so forth. Second, we wanted the object to have the characteristics of a good design, as framed by Norman (2002). Norman (2002) identified discoverability and understanding as the two most important characteristics of good design. Complex products involve discoverability and understanding issues that require more in-depth processes of perception—and even assistance—of the product. Thus, we sought out a "simple thing" (Norman, 2002, p. 3) so that the participants would not spend too much time on understanding the product and could provide more clues about their professional expertise within a limited time span.

The data collection document was a double-sided page with two questions. The first question asked students to provide a "written exploration and analysis" of the object that they were given. This was an open-ended question and students had a one-and-a-half-page box to reflect their thoughts. We preferred this type of analysis over interviews as students would have time to reflect on their ideas without the pressure of interacting with someone or feel a need to keep talking.

The second question was structured as a triangulating question. We aimed to test if our qualitative analysis would overlap with quantitative results. Students were asked to come up with 5 keywords that they associated with the product. This question was developed in line with the free listing method that is used in anthropology (Bernard et al., 2016; Schrauf & Sanchez, 2008; Weller & Romney, 1988). Free lists are advantageous as a first step in identifying participants' knowledge of a cultural domain (Weller & Romney, 1988). In free listing, participants are asked to list all the items that they relate to a domain. In addition to identifying a domain, this also gives researchers the chance to make comparisons among groups (Thompson & Juan, 2006). We applied a modified version of free listing. We limited the number of items (i.e., keywords) as we were mostly interested in the priority that students of different levels gave to certain issues.

The data was collected on the first day of each level's fall semester studio course. Participation in the study was on a voluntary basis. Prior to data collection, students were given consent forms which also explained that the participation would not have an effect on the course content and the evaluation of the course. In fact, the data collection documents were submitted anonymously. Students were given 20 min to complete the task of evaluating the given object. No instructions were given to students during this time in order not the influence their evaluation.

Our data analysis involved both qualitative and quantitative methods. The annotations (students' answers to the first question) were converted into a digital format and coded using Nvivo following the initial and focused coding procedures defined by Charmaz (2006). The lists of keywords provided by students were analyzed using Excel with the add-in Flame v1.2, a tool specifically developed for analyzing free lists. Before the analysis, we combined the keywords on the basis of morphological derivatives (e.g. mass production and mass-production), synonyms (e.g. mass production and quantity production) and identical meanings (e.g. easy to use and user-friendly). As a means of considering the salience in the keyword lists, we reported our findings with the Smith index and Sutrop index, both of which are instrumental for considering both frequency of occurrence and ranking in the list (Borgatti, 2015).

Study context and participant profiles

The study was conducted at a private university which offers a 4 year undergraduate product design program in which students are required to take 4 to 7 courses (equivalent to 30 European Credit Transfer and Accumulation System credits) each semester.

Even though there is no absolute distinction between the pedological approaches in design education, Meyer and Norman (2020) classifies educational approaches in design into two types. Stand-alone schools of art and design usually follow the arts and crafts tradition which focuses on teaching form, aesthetics, materials, and domain-specific skills. On the other hand, design schools and departments located in full-service universities, aim to provide a much broader and richer education by integrating the knowledge of science, technology, people, and society into the design education.

The product design department in the present study resembles the institutions that have a broader perspective towards design education with the integration of the knowledge from science, technology, people, and society. Curriculum involves domain-specific skill-oriented courses (e.g. visualization techniques), courses aiming to build knowledge in diverse disciplines (such as management and consumer behavior), and studio courses in which all knowledge and skills are expected to be reflected into a design practice.

In the studio courses, the students are assigned projects with increasing complexity from the first to last year of their university education. The studio course in the first semester introduces the students to the elements and principles of design. In the second semester, the students are assigned product design problems that are less complicated (e.g. dish dispenser racks). These courses are supported by domain-specific skill-oriented courses such as technical drawing, visualization techniques, and model making.

The second-year studio courses focus on basic form-function-use relationships. The departmental courses in the second year include human factors, structural design, and digital modeling. Starting from the third year, the students are assigned studio projects that require more systematic inquiry of user needs and wants as well as social, cultural, business, and environmental issues. These expectations are supported with theoretical courses on marketing and management. In the last year, the studio projects become more complex as they include product-service systems. Courses such as design research and professional practices are included in the last year of the curriculum.

The age of the students enrolled in the program ranged between 17 and 25. During our study, there were 155 students enrolled in all 4 years of the studio courses. The largest number of students was in the first year and the lowest number of students in the last year (Table 1). Among those students, 107 (69%) were females and 48 (31%) were males. The ratio of females to males was lowest in the fourth year and highest for the third year (2.0, 2.8, 3.0, and 1.4, in the order of the education level). None of the students had prior formal education on design. As the university is a private institution which require much higher tuition compared to public universities, most of the students came from similar economic backgrounds.

Table 1 The number and percentages of participants

Grade level	Number of students
1	48
2	41
3	37
4	29
Total	155
Annotation	
Number of participants	Participation percentage (%)
41	86
29	71
33	89
26	90
129	83
Free listing	
Number of participants	Participation percentage (%)
33	69
29	71
32	87
26	90
120	77

Results

The data collection required that students record their product evaluations on the data collection sheet. None of the students utilized sketches in their analyses. This is not unexpected as the question asked students to provide written exploration but not making an analysis using sketches. In the written analyses, the average number of words used by students did not have a lot of variation (111, 108, 126, and 108, respectively). However, there were notable issues concerning the content of the evaluations.

Students from all grades primarily evaluated the product based on its physical properties and performance. Among the first-year students, the evaluations generally took the form of product description stating what was observable. For example, a student wrote: "This is a FABER CASTEL Model 1440 pen. It consists of three parts: a plastic barrel, an ink chamber and a cap." Another student explained the physical properties of the pen as: "It has a hexagonal shape that gets round towards the tip." These examples illustrate the tendency of the students with no formal design experience to focus on product properties that are easy to observe. Some students even explicitly wrote about how they noticed some physical characteristics (e.g. the hole in the barrel) for the very first time during their analyses. While the first-year students spent most of their space for describing the pen, they rarely related physical properties to other aspects of the product. In this sense, students showed limitations in terms of synthetic capabilities.

In addition to descriptions, another common pattern in the first-year students' evaluations was the inclusion of subjective evaluations. These subjective statements mostly start with "I" and indicate personal preferences and thoughts. For example;

> "… I guess this model is useful for people who wear shirts with pockets, but I keep my pens in a case, so it is not useful for me."
> "I do not find it aesthetically pleasing."
> "I like that the barcode and the brand name are written with a paint that does not easily wear off."

The synthetic capabilities of the second-year students showed improvement. While they also focused on describing the physical properties of the pen, their descriptions were mostly followed by functional explanations addressing the product's performance. They were better in terms of relating physical properties, such as form and texture, to comfort and use. For example, the students who wrote about the texture of the barrel also discussed its possible advantages in terms of minimal slippage. Others who pointed out that the pen had a transparent barrel added that it was useful as it showed how much ink was left. However, the tendency towards evaluating the product's parts individually continued in the second-year students. They rarely correlated form and function of those parts to each other. They also had limited terminological expertise. They used terms like the "bumpy place where the fingers hold the pen" and "non-slippery material." The main terminological development was observable in relation to manufacturing in the second year, as indicated by the fact that terms such as "mould line" and "manufacturing defects" were used in the descriptions.

Student annotations showed the biggest difference between the second- and third-year students. That difference was reflected both in the content of the annotations and the character of the statements. In terms of content, the third-year students used more terminological expressions such as "hand anthropometry" and "extruded surfaces." There was also improvement in their reasoning capabilities. Rather than focusing exclusively on physical descriptions, they tended to describe the product in relation to factors such as user, form, and material.

Among those three factors, user was dominant. That factor was also presented with an emphasis on marketing. Students made references to target users and market segments and made comments like “it is suitable for all segments,” “this would appeal to general usage and user groups” and “this pen would meet the expectations of its target segment.” We also found references to the context in which the pen would be found: “This pen gives me the impression that it can be readily found on desks at workplaces or any other work environment.”

The user was also instrumental in students’ assessments of the pen. Similar to design critiques that take place in jury presentations, the students provided product evaluations in the form of scenarios that focused either on a positive or a negative aspect of the design solution. For example, a student made the following critique in reference to possible user preferences for holding a pen: “While the rough surface of the body indicates how to hold the pen, the edges might hurt your hand if you hold the pen differently.” In another scenario, a student questioned the user’s attachment to the pen and claimed, “This object may not create a relationship with the user. It may not excite the user, or the user may not feel a need to search for the pen if they lose it.”

In general, product attachment was brought up as a shortcoming. The students assessed the inability of the pen to create user attachment because of its generic form and its widespread availability on the market. The students said that users would be unwilling to take care of this pen and they would not feel upset if they lost it. For them, this was partly because of the market placement of the pen. They considered the pen to be “cheap and purpose-oriented.” While making such assessments, they seemed to make a comparative assessment of the pen in relation to other products available on the market: “There are more special pens, and this pen does not have such qualities.”

Different from the first- and second-year students, the third-year students assessed the product with reference to product semantics. One student wrote, “the user’s ability to understand [the message of the product’s form] is important.” In order to evaluate such matters, the students related the product’s form and qualities to the purpose of the message they communicate:

> “This pen is successful in terms of explaining itself. The rough surface shows how to hold the pen.”
>
> “The sound that we hear when placing the cap on shows the user that it is safely locked in place.”
>
> “… there are ridges on the back cap which show me how to turn and replace the cartridge if the ink runs out.”
>
> “The material of the product gives the message that the product is cheap.”

In parallel with the significance given to product semantics, students’ statements include references to design processes, especially in terms of the existence of a decision maker (a designer) in those processes. For example, while the first-year students only wrote about the pen being hexagonal in shape, the third-year students explained that the form is “extruded in a hexagonal shape.” Similarly, another student wrote: “They made use of color to differentiate the pen and the cap. They made the cap blue in order to indicate the ink color. They also made the pen transparent to keep the cost low and to show the ink level.”

These types of references to decisions made by an authority or authorities (i.e., designer or designers) in the product development process also indicate students’ better recognition of various factors (e.g. manufacturing methods, target cost) that influence design decisions.

Another student's comment supports this observation: "Because of the cheap manufacturing, it can be widely used and preferred more in the market."

We also noted that a larger number of the third-year students offered possible design improvements. For example, a third-year student shared his design idea and wrote, "it would have been much better to have a softer piece where we grip the pen." Another one explained "… since the whole relationship of the pen is with the hand, I think a form that better fits the geometry of the hand, a form that does not feel uncomfortable and is suitable for long-term use, would be more efficient."

The tendency to offer design improvements was more common among the fourth-year design students. For example, some fourth-year students suggested using a different color for the text on the main body of the pen (in order to increase the contrast), others suggested making the pen either shorter or thicker to make it easier to grip, and still others offered a different cap design. In general, the suggestions for design improvements were based on personal preferences, ergonomic experiences, or cost reduction.

While both the third- and fourth-year design students offered design improvements, students in the fourth year were also more inclined to include a problem definition. For example, "This product was designed for rapid consumption and usage" and "The aim was to serve the basic function without addressing personal preferences." Rather than offering a general problem definition, some students also explained potential issues such as the potential for the cap and the grip to accumulate grime.

Among the students from all 4 years, the fourth-year students focused the most on manufacturing and utilized more professional expressions in relation to production processes. Terms such as mass production, plastic injection, and injection molding appear in almost half of the descriptions. Some even wrote about the parting line and the holes resulting from injection molding. These students seemed to be more conscious about the impact of the manufacturing process on design decisions.

The fourth-year students also tended to be more detail oriented and focused on form related details. For example, "In order to ease the process of clipping the cap to different surfaces, the edge of the clip was curved" and "The area between the clip and the cap was made thicker in order to prevent breakage."

A quantitative analysis of the keyword lists also revealed patterns that fit our qualitative findings. We received a total of 592 keywords from the participants. Among them, there were 174 different words/phrases. The number of different keywords offered by each cohort showed slight differences; 71, 76, 67, and 66 different keywords were provided, respectively.

Table 2 lists the keywords that were mentioned by at least 10% of students from each level. We preferred to report based on frequency, as number of participants from each level was not equal. We selected 10% as the cut-off point for two reasons. First, as we are interested with the commonalities within the group, we aimed for further analyzing keywords that were mentioned more than one participant from each group (which is less than 5%). Second, we analyzed keywords with using 5% as a cut-off as well and did not observe any significant differences between 10% and 5% in terms of our results.

While most of the keywords matched among groups, there were also differences. Keywords related to human factors such as ergonomics and usability appeared among the responses of the second-year students. Mass production, however, was mentioned only by the fourth-year year students. The economic aspect of the pen being "cheap" entered the list among second-year students and moved to the top in the descriptions of students from the third- and fourth-year groups.

Table 2 Keywords that were mentioned by at least 10% of the participants from each grade level

	Keyword	Occurrence	Frequency (%)	Average rank	Smith index	Sutrop index
	First year					
1	Blue	16	48.48	2.5	0.339	0.194
2	Pen	11	33.33	2.273	0.249	0.147
3	İnk	11	33.33	3.364	0.18	0.099
4	Plastic	10	30.30	2.2	0.23	0.138
5	Ball-point	6	18.18	2.167	0.139	0.084
6	Transparent	6	18.18	2.333	0.133	0.078
7	Functional	5	15.15	3	0.086	0.051
8	Simple	5	15.15	3.2	0.085	0.047
9	Writing (verb)	5	15.15	3.8	0.069	0.04
10	Faber-Castell	4	12.12	2	0.097	0.061
11	Cap	4	12.12	3.25	0.067	0.037
12	Stiff	4	12.12	3	0.073	0.04
13	Writing (noun)	4	12.12	3.5	0.061	0.035
	Second year					
1	Blue	10	34.48	2.9	0.2	0.119
2	Ink	9	31.03	2.333	0.228	0.133
3	Transparent	9	31.03	3.111	0.179	0.1
4	Writing (noun)	6	20.69	3.167	0.121	0.065
5	Light	5	17.24	4	0.069	0.043
6	Cheap	5	17.24	4.2	0.062	0.041
7	Ball-point	5	17.24	2.8	0.11	0.062
8	Plain	4	13.79	3	0.083	0.046
9	Plastic	4	13.79	2	0.097	0.069
10	Simple	3	10.34	3	0.062	0.034
11	Ergonomic	3	10.34	3.333	0.055	0.031
12	Writing (verb)	3	10.34	1	0.103	0.103
	Third year					
1	Simple	15	46.88	2.267	0.353	0.207
2	Cheap	13	40.63	2.846	0.256	0.143
3	Usable	7	21.88	3.286	0.122	0.067
4	Blue	7	21.88	2.571	0.153	0.085
5	Uncomfortable	6	18.75	1.833	0.156	0.102
6	Plain	5	15.63	2.6	0.109	0.06
7	Stiff	5	15.63	3.4	0.081	0.046
8	Common	5	15.63	3.4	0.081	0.046
9	Transparent	5	15.63	4	0.067	0.039
10	Geometric	4	12.50	2	0.1	0.063
11	Light	4	12.50	3.25	0.069	0.038
12	Long lasting	4	12.50	3.25	0.074	0.038
13	Standard	4	12.50	3.75	0.056	0.033
14	Plastic	4	12.50	2.5	0.091	0.05
	Fourth year					
1	Cheap	13	50.00	2.538	0.337	0.197

Table 2 (continued)

	Keyword	Occurrence	Frequency (%)	Average rank	Smith index	Sutrop index
2	Blue	8	30.77	2	0.25	0.154
3	Simple	6	23.08	2.167	0.177	0.107
4	Mass production	5	19.23	2.6	0.121	0.074
5	Transparent	4	15.38	2.75	0.101	0.056
6	Ball-point	4	15.38	3.25	0.087	0.047
7	Light	4	15.38	3	0.092	0.051
8	Economic	4	15.38	2.75	0.098	0.056
9	Classic	3	11.54	4.333	0.038	0.027
10	Cap	3	11.54	4.333	0.038	0.027
11	Stiff	3	11.54	3.667	0.05	0.031
12	Functional	3	11.54	1	0.115	0.115
13	Common	3	11.54	2	0.087	0.058

We further coded the keywords either being description- or opinion-based. The keywords labelled under description-based mostly reference the physical attributes of the object such as parts, materials, form, and function. Opinion-based keywords involve the participant's subjective evaluation of the product. These evaluations appear to be in two ways. First, participants commented on their experience of the product itself. Participants expressed the appearance of the product (e.g. "plain", "simple"), the sensual feedback through the product-user interaction (e.g. "light", "stiff"), and the product's use performance (e.g. "uncomfortable", "usable"). Second, participants evaluated the object in relation to their experience with similar products. They used keywords such as "standard" and "common". These keywords are mostly based on the basic impressions and experiences of the product, rather than more elaborate examination of the product.

In terms of the distribution of keywords, we noticed a change from the second to third year. While the first- and second-year students provided more keywords that described the physical quality of the product, the keyword list for the third-year students has more terms relating to their opinions regarding the product. For the fourth-year students, the percentages of descriptive and opinion-based keywords are almost equal.

Discussion

Development of design expertise relies on the development of cognitive skills and the development and integration of domain knowledge (Lawson & Dorst, 2009). The comparison of students' product evaluations indicates clues regarding the development pattern of design expertise.

Without domain-specific knowledge, cognitive skills and experience, first year students tend to evaluate product with commonsense knowledge. Supporting Cross' (2004) and Popovic's (2004) comments, due to the lack of analyzing capabilities they recognize superficial features of the product but in rather detailed and specific manner. Their evaluations are limited to descriptions of product properties that are easy to observe. There was no further analysis associating those properties to other aspects of the product. In this sense, the reasoning capabilities of first year students are limited.

As they acquire basic knowledge and cognitive skills of the domain in the first-year courses, the second-year students' reasoning capabilities start to improve. Yet, their synthetic capabilities are limited to associating product's physical properties to product's performance (e.g. comfort). They still lack a holistic perception of the product and use of terminological expressions.

A significant transition occurs starting from the third year. This transition might be interpreted in reference to findings from previous studies. Parallel to increase in domain-specific knowledge acquisition and engagement with more complex design problems in studio courses, students' critical thinking and problem-solving capabilities improve over the years of their education (Cross et al., 1994). They are more confident in prioritizing and associating relevant knowledge to develop strategies for solving a problem (Lawson & Dorst, 2009). As a reflection of these changes, we observed that students move beyond associating physical property only with the product's performance and start to evaluate product in relation with users, materials and manufacturing methods. User involvement presents itself in marketing, ergonomics, and communicative properties of the product. They start to develop holistic understanding of the product with its practical, aesthetic, and symbolic functions. Third year students start to develop critical thinking and professional assessment. They go beyond analyzing and explaining product properties and performance, they start to question them. There is also a significant improvement in terminological expressions of the students in the third year.

Fourth-year students propose design alternatives more than other students. They pay more attention on feasibility and realization of product. They consider how design decisions are in relation with materials, manufacturing, and detailing. Thus, the synthetics capability of fourth-year students is more observable.

These descriptive findings exemplify Krippendorff's (1989, 2006) claim about sense-making differences between designers and non-designers. The differences among students' descriptions indicate a shift from ordinary to professional sense-making from first year to last year. Three main points seem to be particularly relevant in their professional sense-making when the first-year students are compared to the fourth-year students.

First, the students in later years seem to depend more on subjectivity rather than objectivity. There is an observable increase in the number of opinion-based keywords in the third and fourth year. These opinion-based assessments are also observable in students' annotations. Their assessments are not limited to personal experiences with the product. They make professional judgements as well. For example, some students evaluated the product in reference to other products within the same product category, others utilized domain-specific knowledge on materials, manufacturing, and user-product interaction for assessment. These observations can be interpreted as an increase in domain-specific judgmental capabilities as students' journey in the product design education progresses. This is in line with findings from previous studies (Casakin, 2010; Cila et al., 2014) that claim experienced designers make better judgement on domain-specific issues as a result of their experiential knowledge in the domain. Thus, students start to rely on their judgements more confidently.

Students' statements that describe product designer as a decision maker also support our observation of students' dependence more on subjectivity in the later years of product design education. In the third year, students make statements about design being a process. They use "making" and "doing" more frequently. In their statements, the designer stands out as an authority in this making and doing processes. Instead of describing the factual properties of the product by means of form, material, use, production, and so forth, students define the reasons for the product to have such factual properties. They also start to question these decisions. Some third- and fourth-year students provided alternative design solutions in their product evaluations. This finding might be interpreted to support the literature (e.g. Cross, 2004) that indicates that expert designers have a tendency to start developing possible solutions early in the design process. However, it is also important to note that students were not provided with any user or market research data related to the assigned object. This finding can also mean that more experienced students tend to trust their subjectivity in the development of design solutions. It follows that there is a transition from a descriptive, interrogative, and analytical attitude to a prescriptive and suggestive attitude as students move through the years of product design education.

The second issue that defines professional sense-making in product design can be described in relation to the significance given to users. References to users were made mostly in relation to two issues, product semantics and user scenarios. Product semantics was more dominant. The third-year students and fourth-year students took up the issue of users in order to evaluate the communicative character of the form. Students evaluated the product mostly in relation to its form, as well as functionality and usability as an outcome of the form. Our findings support previous comments of Findeli (2001), Krippendorff (2006), and Norman (2010) asserting that product design education focuses more on the form. The second issue is the students' utilization of users as actors. Later year students' annotations included scenarios in which they explained how a user interacts with the pen. They used these scenarios as a tool to assess the artifact that they were given. For this reason, we interpret that users play a greater role for expert designers in assessing design solutions.

The last pattern in the students' product evaluations indicates that assessments of products are made more in relation to the synthetic capabilities in the later years of design education. The lack of perceiving the product as a whole seemed to prevent the first- and second-year students from analyzing the overall experience of the product in terms of its practical, aesthetic, and symbolic functions. The issues related to the synthetic capabilities arose in two ways. First, while the first-year students' statements mostly provided a bare description of the physical properties of the product, in later years—especially starting in the third year—students started discussing the different parts of the pen in relation to each other (e.g. use of the same color on the cap and the rear stopper). Second, students were better able to relate the different aspects of the product (e.g. material selection in relation to cost or texture selection in relation to enhanced usability) in later years. Our findings suggest that synthetic capabilities develop gradually as the students advance from being novices to experts. While the statements of the first-year students were limited to descriptions, in the second year those descriptions were often followed by discussions of functionality. In the third year, students also explained how they relate the form of the product to ease of use. Their critical thinking, reasoning, and constructive capabilities showed major improvement. The fourth-year students added manufacturing to their explanations. They made more references to manufacturing methods and related the selection of materials to manufacturing methods and costs.

While these three main points seem to be instrumental in the professional sense-making of student designers, we were surprised by the lack of development in professional terminology. The lack of professional terminology becomes especially relevant in relation to students' explanations of product forms. The students used terms such as "horizontal hollows" and "rough surfaces" to explain the form of the product regardless of how long they had been studying. The students' inability to advance their descriptions of form indicates a lack development of disciplinary vocabulary.

Our findings indicate the impact of courses other than studio on students' product perception as well. Students' perceptual development in relations to users, materials, manufacturing can partially be related to the program curriculum. Similarly, during the time of data collection, the product design curriculum in the studied university did not offer any courses on design ethics, sustainability, or designer's responsibility for the social and environmental impacts. On the other hand, these issues were highly considered topics in studio critics. Yet, our findings indicate that the students presented lack of expertise development in these issues. The evaluated product was a non-reusable pen. However, only very few of the students discussed it in relation to environmental aspects. Some even commented on the lack of user attachment to the pen and the potential lack of a desire to search for it if it were to be misplaced. This might be interpreted as a need for the inclusion of theoretical courses on design ethics in undergraduate product design education.

Limitations

We aimed to take another perspective towards analyzing the impact of undergraduate product design education on the development of design expertise. Rather than exploring how novices versus experts approach various aspects of designing, we comparatively analyzed how they perceive an existing design solution. While our methodological approach gave us the chance to further discuss the development of design expertise in relation to critical thinking, it could have affected our results as we only used written data.

As we sought to compare students' design expertise, we conducted a cross-sectional study at a single university. However, there may be unobserved sources of variation (e.g. social characteristics, educational background prior to undergraduate program, previous exposure to design). For this reason, we do not have causal claims about the progression of expertise through the years.

As the study was conducted in the first semester, the first-year students represent a sample for participants with no formal design education at university level. On the other hand, our findings do not include data from students who completed a product design program. In the future, it might be necessary to collect data from fourth-year students at the end of the academic year as well.

While we are aware that the students' acquisition of design expertise could have been framed with the analysis of a wide range of objects, we conducted our study with a single object. This object might have played a role in students' excessive attention to form and functionality rather than other design issues. We believe it might be useful to repeat the study in the future with objects from other product categories for comparative purposes.

Our data collection experience illustrated the significance of distributing the object of analysis to each participant rather than showing the pictures of the object. This gave the chance for participants to better interact with the object for evaluation. On the other hand, in the future, we will explicitly express to the participants that the evaluations via sketches are welcome as well. This will give us a chance to share another level of data.

Conclusion and future work

Our study on students' product perception indicates that the biggest difference exists between the second to the third-year students. Starting in the third year, students' professional sense-making becomes more evident in their product evaluations. Three main issues define this professional sense-making: a dependency on subjectivity, the significance given to users, and better synthetic capabilities that are built around form, material, manufacturing, and detailing relationships.

Our data comes from a single case, a product design department from a full-service university. We acknowledge that it is necessary to conduct further studies at other product design departments. This is necessary for the generalizability of our findings. While doing so, we plan to conduct the same study at product design departments with arts and crafts tradition as well. This will enable to assess us the impact of different educational approaches, as framed by Meyer and Norman (2020), on students' product perception.

Studies on expertise have longer history in some other fields. While the existing body of design expertise literature builds upon studies from these other fields (Tan, 2021), in this paper, we focused on design expertise in relation to product design education without taking a comparative approach. In the future, we plan to discuss the implications of our findings to broader expertise literature and conduct comparative studies with students from other disciplines in order to claim that our conclusions are unique to product design.

References

Ahmed, S., Wallace, K. M., & Blessing, L. T. (2003). Understanding the differences between how novice and experienced designers approach design tasks. *Research in Engineering Design, 14*(1), 1–11.

Akin, Ö., & Lin, C. (1995). Design protocol data and novel design decisions. *Design Studies, 16*(2), 211–236.

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher, 32*(8), 10–14.

Bargh, J. A., & Ferguson, M. J. (2000). Beyond behaviorism: On the automaticity of higher mental processes. *Psychological Bulletin, 126*(6), 925–945.

Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. *American Psychologist, 54*(7), 462–479.

Bartram, D. (1982). The perception of semantic quality in type: Differences between designers and non-designers. *Information Design Journal, 3*(1), 38–50.

Bernard, H. R., Wutich, A., & Ryan, G. W. (2016). *Analyzing qualitative data: Systematic approaches*. Sage.

Björklund, T. A. (2013). initial mental representations of design problems: Differences between experts and novices. *Design Studies, 34*(2), 135–160.

Blijlevens, J., Crusen, M. E. H., & Schoormans, J. P. L. (2009). How consumers perceive product appearance: The identification of three product appearance attributes. *International Journal of Design, 3*(3), 27–35.

Borgatti, S. P. (2015). Sofware review: FLAME (version 1.1). *Field Methods, 27*(2), 199–205.

Boshuizen, H. P. A., Bromme, R., & Gruber, H. (2004). On the long way from novice to expert and how travelling changes the traveller. In H. P. A. Boshuizen, R. Bromme, & H. Gruber (Eds.), *Professional learning: Gaps and transitions on the way from novice to expert* (pp. 3–8). Kluwer Academic.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues, 8*(2), 5–21.

Buchanan, R. (2001). The problem of character in design education: Liberal arts and professional specialization. *International Journal of Technology and Design Education, 11*(1), 13–26.

Casakin, H. (2010). Visual analogy, visual displays, and the nature of design problems: The effect of expertise. *Environment and Planning b: Planning and Design, 37*(1), 170–188.

Casakin, H. (2011). Metaphorical reasoning and design expertise: A perspective for design education. *Journal of Learning Design, 4*, 29–38.

Charmaz, K. (2006). *Constructing grounded theory: A practical Guide through qualitative analysis*. Sage.
Cila, N., Hekkert, P., & Visch, V. (2014). "Digging for meaning": the effect of a designer's expertise and intention on depth of product metaphors. *Metaphor and Symbol, 29*(4), 257–277.
Collins, H., & Evans, R. (2009). *Rethinking expertise*. University of Chicago Press.
Cross, N. (1990). The nature and nurture of design ability. *Design Studies, 11*(3), 127–140.
Cross, N. (2004). Expertise in design: An overview. *Design Studies, 25*(5), 427–441.
Cross, N. (2018). Expertise in professional design. In A. M. Williams, A. Kozbelt, K. A. Ericsson, & R. R. Hoffman (Eds.), *The cambridge handbook of expertise and expert performance* (2nd ed., pp. 372–388). Cambridge University Press.
Cross, N., Christiaans, H., & Dorst, K. (1994). Design expertise amongst student designers. *Journal of Art & Design Education, 13*(1), 39–56.
Desmet, P., & Hekkert, P. (2007). Framework of product experience. *International Journal of Design, 1*(1), 57–66.
Dorst, K., & Reymen, I. (2004). Levels of expertise in design education. In *Proceedings of E&PDE 2004, the 7th international conference on engineering and product design education* (pp. 159–166). Delft
Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over machine: The power of human intuition and expertise in the era of the computer*. Free Press.
Eyal, G. (2019). *The crisis of expertise*. Polity Press.
Findeli, A. (2001). Rethinking design education for the 21st century: Theoretical, methodological, and ethical discussion. *Design Issues, 17*(1), 5–17.
Firth, R., Stoltenberg, E., & Jennings, T. (2016). Using an outdoor learning space to teach sustainability and material processes in HE product design. *International Journal of Art & Design Education, 35*(3), 327–336.
Friedman, K. (2003). Theory construction in design research: Criteria: Approaches, and methods. *Design Studies, 24*(6), 507–522.
Gray, C. M. (2019). Revealing students' ethical awareness during problem framing. *International Journal of Art & Design Education, 38*(2), 299–313.
Green, L. N., & Bonollo, E. (2004). The importance of design methods to student industrial designers. *Global Journal of Engineering Education, 8*(2), 175–182.
Heufler, G. (2004). *Design basics: From ideas to products*. Niggli Verlag.
Hsu, S. H., Chuang, M. C., & Chang, C. C. (2000). A semantic differential study of designers' and users' product form perception. *International Journal of Industrial Ergonomics, 25*(4), 375–391.
Irwin, T. (2015). Transition design: A proposal for a new area of design practice, study, and research. *Design and Culture, 7*(2), 229–246.
Kokotovich, V. (2008). Problem analysis and thinking tools: An empirical study of non-hierarchical mind mapping. *Design Studies, 29*(1), 49–69.
Krippendorff, K. (1989). On the essential contexts of artifacts or on the proposition that "design is making sense (of things)." *Design Issues, 5*(2), 9–39.
Krippendorff, K. (2006). *The semantic turn: A new foundation for design*. CRC Press.
Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: Strategies and outcomes. *Design Studies, 27*(5), 527–548.
Lawson, B. (1990). *How designers think* (2nd ed.). Butterworth Architecture.
Lawson, B., & Dorst, K. (2009). *Design expertise*. Architectural Press.
Lloyd, P., & Scott, P. (1994). Discovering the design problem. *Design Studies, 15*(2), 125–140.
Lu, C.-C. (2017). Interactive effects of environmental experience and innovative cognitive style on student creativity in product design. *International Journal of Technology and Design Education, 27*(4), 577–594.
Manzini, E. (2019). *Politics of the Everyday*. Bloomsbury Visual Arts.
McDonagh, D., Thomas, J., & Strickfaden, M. (2011). Empathic design research: Moving towards a new mode of industrial design education. *Design Principles and Practices: An International Journal, 5*(4), 301–313.
Meyer, M. W., & Norman, D. (2020). Changing design education for the 21st century. *She Ji: The Journal of Design, Economics, and Innovation, 6*(1), 13–49.
Norman, D. (2002). *The design of everyday things*. Basic Books.
Norman, D. (2010). Why Design Education Must Change. *Core77*. Retrieved from 18 June 2015 http://www.core77.com//posts/17993/Why-Design-Education-Must-Change
Popovic, V. (2004). Expertise development in product design—Strategic and domain-specific knowledge connections. *Design Studies, 25*(5), 527–545.
Redström, J. (2006). Towards user design? On the shift from object to user as the subject of design. *Design Studies, 27*(2), 123–139.

Rowe, P. G. (1987). *Design thinking*. The MIT Press.
Schrauf, R. W., & Sanchez, J. (2008). Using freelisting to identify, assess, and characterize age differences in shared cultural domains. *The Journals of Gerontology: Series B, 63*(6), S385–S393.
Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin, 119*(1), 3–22.
Tan, S. (2021). Towards an integrative approach to researching design expertise. *Design Studies, 74*, 1–28.
Thompson, E. C., & Juan, Z. (2006). Comparative cultural salience: Measures using free-list data. *Field Methods, 18*(4), 398–412.
Tynjala, P. (1999). Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. *International Journal of Educational Research, 31*(5), 357–442.
Wang, C.-Y. (2020). Differences in perception, understanding, and responsiveness of product design between experts and students: An early event-related potentials study. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-020-09592-z
Weller, S. C., & Romney, A. K. (1988). *Systematic data collection*. Sage.
Wong, J.-J., Chen, P.-Y., & Chen, C.-D. (2016). The metamorphosis of industrial designers from novices to experts. *International Journal of Art & Design Education, 35*(1), 140–153.
Yang, C., Liu, Z., Wang, H., & Shen, J. (2013). Reusing design knowledge based on design cases and knowledge map. *International Journal of Technology and Design Education, 23*(4), 1063–1077.