Measuring the Impact of Integrating Human-Centered Design in Existing Higher Education Courses

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The purpose of this research is to describe the development of a survey that can be used to measure the impact of integrating Human-Centered Design (HCD) on students' knowledge of performing its processes in existing higher education courses. The survey was developed based on a research-based HCD taxonomy that outlines the design spaces, the processes, and practices that define what it means for students to implement HCD within the context of k-12 or higher education settings. The survey consisted of 23 items and was pilot tested with 46 students. Validity and reliability analyses were conducted, and the survey items were revised in light of the findings. More items were also added to the existing survey. The development and use of this survey can promote efforts of scaling the integration of HCD in existing higher education courses.

Keywords: human-centered design, survey, higher education

Introduction

Human-Centered Design (HCD) is a problem-solving approach that identifies the unmet needs of a population in order to collaboratively and iteratively develop solutions (Brown, 2008). In the past decade, there has been an increasing trend of teaching and learning HCD in higher education settings (Ching, 2014; Kumar et al., 2020; Lin et al., 2020) given its promising potential to prepare students for engaging effectively in future learning endeavours and participating actively in solving todays' global challenges.

Several research studies show that when students engage in learning and implementing HCD processes, they develop 21st century skills such as solving complex problems and working in multidisciplinary teams (Koh et al., 2015; Noweski et al., 2012). Eventually, as students practice these skills, they develop critical mindsets, such as human-centeredness, metacognition, collaboration, experimentation, communication, and creativity (Goldman et al., 2012; Razzouk & Shute, 2012). These mindsets are essential for design and non-design students to become lifelong learners and successfully solve personal and work problems. However, providing students with opportunities to learn and implement HCD processes within the context of higher education courses is challenging (Kumar et al., 2020; Shehab et al., 2021a). One reason for that is our lack of the knowledge of how to effectively integrate HCD in existing higher education courses that are usually subject to many curricular and time constraints. Specifically, little is known about evaluating the impact of integrating HCD on students' knowledge of performing the HCD processes in these courses.

To address this gap, we report how a newly established design center continued to integrate HCD in existing higher education courses at a large Midwestern university. Specifically, in this paper, we describe how we built on the evaluation of our first iteration of integrating HCD in three existing courses (Shehab et al., 2021a) to design a survey that can measure the impact of integrating HCD on students' knowledge of performing the HCD processes. Findings from this work can promote efforts of scaling the integration of HCD in higher education courses by enriching our knowledge of how to effectively measure the impact of HCD activities on students' knowledge of performing its processes in existing higher education courses.

What is Human-Centered Design?

Human-Centered Design is a problem-solving approach that identifies the unmet need of a population in order to collaboratively and iteratively develop solutions (Brown, 2008). HCD puts humans at the center of the design processes and seeks to establish empathy with them, understand them, collaborate with them in order to identify their problems and figure out solutions (Brown & Katz, 2011; Dorst, 2011; Zhang & Dong, 2008). Then, HCD relies on iterative cycles that engage humans in prototyping, testing, and refinement of solutions (Brown, 2008). HCD provides a flexible structure that can guide the processes of solving wicked problems (Buchanan, 1992; von Thienen et al., 2014) and generate creative and meaningful solutions (Meinel et al., 2020). HCD should not be viewed as a predefined sequential series of processes that one initiates to solve a problem; nevertheless, it is best described as "a system of spaces" (Brown, 2008, p.4). Each space consists of processes such as empathize, organize, brainstorm, create, and develop which can be executed by learning and implementing practices such as interviewing people, identifying themes, communicating ideas, creating prototypes and developing plans to bring final designs to the market (IDEO, 2015). Figure 1 shows the HCD taxonomy that summarizes the human-centered design spaces and processes (Lawrence et al., 2021). The definitions and the practices associated with each process are defined in Lawrence et al. (2021).
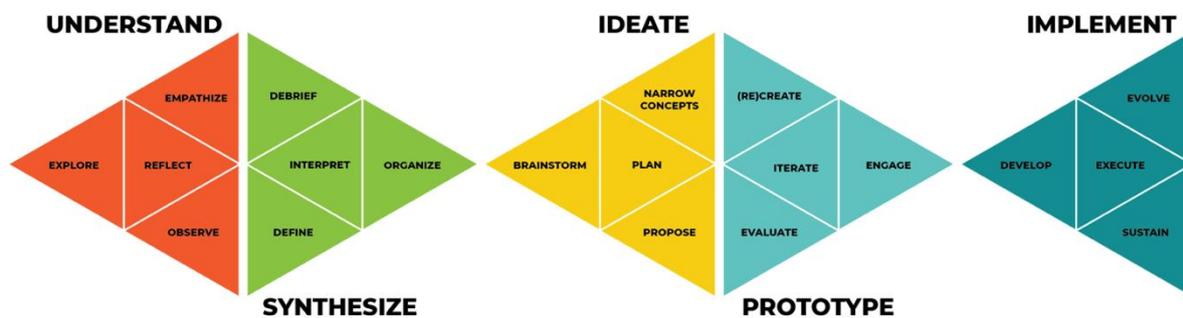

Figure 1. The Human-Centered Design Taxonomy spaces and processes (Lawrence et al., 2021)

Human-Centered Design in higher education settings

Given that HCD is an approach for solving wicked problems and generating innovative solutions, researchers argue it is not only for designers (Johansson-Sköldberg et al., 2013; Wrigley & Straker, 2017). Non-designers can also benefit from implementing and acquiring these processes and practices as they help them develop skills that make them lifelong learners and prepare them to solve complex problems in different contexts (Goldman et al., 2012; Meinel et al., 2020; Razzouk & Shute, 2012). For example, HCD processes and practices engage individuals in finding, discerning and analyzing resources, creating arguments, problem-solving, building and testing models, storytelling, managing time, persisting, and working in teams (Johansson-Sköldberg et al., 2013; Panke, 2019). As individuals learn and practice these skills, they may eventually develop human-centered, metacognitive, collaborative, experimental, creative, and communicative mindsets (Crismond & Adams, 2012; Culén & Gasparini, 2019; Goldman et al., 2012; Razzouk & Shute, 2012; Royalty, 2018). These mindsets match with what employers seek in 21st century employees (Jang, 2016; Prinsley & Baranyai, 2015). In light of that, universities are increasingly investing in integrating HCD in their programs as means for students to experience and develop these mindsets in addition to disciplinary knowledge (Lake et al., 2021; Wrigley & Straker, 2017).

One way to bring HCD to university programs is through integrating it in the content of existing courses, especially those that require students to complete a research or design project over the duration of the semester. In such courses, HCD can serve as a tool for students to complete the project while learning and implementing processes that assist them to a) identify real problems and figure out meaningful solutions that are directly connected to their experiences beyond the course b) learn and practice skills that are essential for developing 21st century mindsets such as collaboration and communication, and c) acquire an understanding of the underlying disciplinary concepts associated with the course. The integration of HCD in these courses is supported by the constructivism learning theory that emphasizes the fundamental roles of prior knowledge, experiences, and social interactions in students' learning processes and outcomes (Bada & Olusegun, 2015; Sjøberg, 2010). Researchers argue that learning and implementing HCD processes enhances students' engagement in constructing knowledge and thought processes using their prior knowledge and experiences and through social interactions which can result in better learning outcomes (Luka, 2020; Pande & Bharathi,

2020; Scheer et al., 2012). Nevertheless, only few studies report on how to effectively integrate HCD in existing higher education courses (Ching, 2014, Pagano, Shehab, & Liebenberg 2020, Shehab et al., 2021a). In addition, little is known about measuring the impact of integrating HCD on students' knowledge of performing its processes in these courses.

The purpose of the current research
The purpose of this research is to describe how a newly established design center at a large Midwestern University developed a survey that can be used to measure the impact of integrating HCD on students' knowledge of performing its processes in existing higher education courses. This survey can be useful for researchers to evaluate the impact of an HCD intervention on students' knowledge of performing HCD processes. Moreover, the survey can be useful for teachers, especially those teaching classes with large number of students, to assess how integrating HCD activities assisted students (or not) in acquiring HCD processes that they may find useful to solve problems beyond the course.

Methods
This research is part of a broader design-based research (McKenney & Reeves, 2012) initiative led by a newly established design center at a Midwestern University. Members from the Center collaborate with instructors across disciplines to explore and harness opportunities of integrating HCD activities into their courses.

Survey development
In the Spring 2019 semester, members from the center collaborated with three instructors to integrate HCD in three different existing courses. The evaluation of integrating HCD in these courses from the students' and instructors' perspectives indicated the need for tools that can assist instructors in communicating what HCD is and ways to measure students' performance and acquisition of the HCD processes (Shehab et al., 2021a). In response, research members form the center developed a research based HCD taxonomy that is shown in Figure 1 (Lawrence et al., 2021). Drawing from the HCD literature, the taxonomy outlines five design spaces, the processes, and practices that define what it means for students to implement HCD within the context of a k-12 or higher education setting. For example, in the Understand space, students try to identify the problem through connecting with the users and thinking about their assumptions and biases. The Understand space is composed of four core processes: Explore, Observe, Empathize, and Reflect. Therefore, for students to Understand the problem, they need to learn and implement the practices associated with each of the four core processes. For example, to Empathize, students need to learn about locating resources, conducting interviews and identifying extreme users; then, they need to implement these practices to make progress on their research or design project.

In the Fall 2019 semester, members from the center collaborated with two instructors to integrate HCD in two different existing courses. The duration of both courses was 16 weeks and they both included a design project that students needed to complete by the end of the course. One course was a technological entrepreneurship course and the other was a food science course. In both courses, the taxonomy was used as a tool for teaching and learning about HCD as a problem-solving approach with processes and practices that students can implement to complete the design project over the duration of the course. The members from the center and each of the instructors co-designed and engaged students in activities to acquire the HCD processes and practices outlined by the taxonomy and implement them to make progress on their design project. The research members from the center needed an instrument to measure the impact of these activities on students' knowledge of performing HCD processes in these courses. They developed a self-administered survey that can be used prior and post any existing course that integrates HCD.

The survey was a 5-points Likert Scale with 1=Strongly Disagree and 5 = Strongly Agree. The items of the survey were developed based on the definitions and practices that are associated with each of the 20 processes that were outlined by the HCD taxonomy based on the HCD literature. The survey had 23 items. Nine items were associated with the processes of the Understand space, three items were associated with the processes of the Synthesize space, four items were associated with the processes of the Ideate space, three items were associated with the processes of the Prototype space, and four items were associated with the processes of the Implement space. The items of the survey are shown later in Table 1.

Participants
A pilot test of the survey was conducted with the students of the two courses. A total of 46 students completed the survey as a pre and post survey prior to and at the end of the course respectively. Using data

from the pilot test, we conducted paired sample t-tests to measure the impact of integrating HCD activities on students' knowledge of performing its processes. We ran a paired sample t-test for each item and for all items associated with the processes of each of the five HCD spaces.

Survey validation

To ensure content validity, experts in HCD were consulted and their input was used to modify some items. We also used data from the pilot test to assess two important qualities of surveys, accuracy and consistency, by considering the survey's construct validity and reliability. Construct validity refers to the extent the survey items measure what they were designed to measure (O'Leary-Kelly & Vokurka, 1998). There are two types of factor analysis to measure the construct validity: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). Because we intent to test whether items could measure students' knowledge of performing processes associated with pre-determined spaces, we conducted confirmatory factor analysis for each item of the pre- and post-survey to examine the construct validity of the survey. To do so, we used lavaan in the R statistical programming language. When testing the model fit, lavaan outputs different fit statistics, we only focused on two commonly used measures: Root Mean Square Error of Approximation (RMSEA) and Confirmatory Factor Index (CFI). As a rule of thumb, a model indicates a good fit when the RMSEA is close to 0.05 but smaller than 0.1 and CFI is greater than 0.90. Reliability refers to the extent the survey items associated with the processes in each space are consistent (Tavakol & Dennick, 2011). We examined the reliability of the survey by computing Cronbach's alpha per each HCD space of the pre- and post-survey. A general acceptable Cronbach's alpha value is from 0.45 to 0.98, and 0.7 or larger indicates a good level (Taber, 2018).

Results

Paired sample t-tests results

To measure the impact of integrating HCD activities on students' knowledge of performing its processes in the two existing higher education courses, we used R to conduct paired sample t-tests. The null hypothesis assumes the mean difference between two sets of observations is zero. When the p-value from the result was smaller than 0.05, we concluded that the difference in the response to an item between pre- and post-survey was significant. Table 1 shows the result of the paired sample t-test for each survey item. All p-values are smaller than 0.05 indicating a significant improvement in students' knowledge of performing the HCD processes.

Table 1. Paired sample t-test per item

Space	Pair	Item	t-value	Sig. (2-tailed)
Understand	1	I know how to develop goals for the project.	-6.75	.000
	2	I know how to review information that is related to the context of the project.	-7.164	.000
	3	I know how to document biases and predictions.	-4.388	.000
	4	I know how to conduct interviews with users.	-8.871	.000
	5	I know how to conduct observations that can inform my understandings of the users' needs.	-7.485	.000
	6	I know how to locate resources that are associated with the project.	-2.979	.005
	7	I know how to identify extreme users.	-9.513	.000
	8	I know how to reflect on my biases.	-3.392	.001
	9	I know how to reflect on the projects' motivations and stakeholders' needs.	-5.051	.000
Synthesize	10	I know how to filter content for relevance and prioritize information.	-4.463	.000
	11	I know how to find themes and develop insights.	-5.745	.000
	12	I know how to identify design and research opportunities.	-4.676	.000
Ideate	13	I know how to come up with ideas for potential solutions to a problem.	-3.341	.002
	14	I know how to break down a problem into smaller actionable parts.	-3.747	.001
	15	I know how to develop a plan of action to solve a problem.	-4.505	.000
	16	I know how to come up with alternative solutions to a problem.	-4.129	.000
Prototype	17	I know how to create a prototype.	-5.521	.000
	18	I know how to communicate a proposed prototype to others.	-5.896	.000
	19	I know how to evaluate a prototype.	-4.638	.000
Implement	20	I know how to communicate a final design.	-6.556	.000
	21	I know how to develop a plan to execute a final design.	-5.874	.000
	22	I know how to create a functional iteration of a concept.	-6.627	.000
	23	I know how to plan for the sustainability of a final design.	-7.101	.000

Following the same analysis procedures, Table 2 shows the result of the paired sample t- test for each HCD space. All p-values are also smaller than 0.05 indicating significant improvement in students' knowledge of performing the HCD processes associated with each of the five HCD spaces.

Table 2. Paired t-test for each space

Pair	Space	t-value	Sig. (2-tailed)
1	Understand	-10.277	.000
2	Synthesize	-6.281	.000
3	Ideate	-5.534	.000
4	Prototype	-5.990	.000
5	Implement	-8.75	.000

Validity and reliability test results

To assess validity, we calculated the confirmatory factor index (CFI) and the Root Mean Square Error of Approximation (RMSEA) for the pre and post surveys (see Table 3). For pre-survey, both the CFI and RMSEA values indicated that the model was not fit. For post-survey, the CFI and RMSEA values were better than the pre-survey, however, the model was still not fit. This indicated that the items of different spaces may need further modifications, so they measure exactly what we want them to measure.

Table 3. Assessment of survey validity

Survey	CFI	RMSEA
Pre	0.693	0.13
Post	0.827	0.095

To assess reliability, we used Cronbach's Alpha to measure the consistency of the survey items per each of the five spaces. Based on the values of Cronbach's Alpha shown in Table 4, both the pre- and post- survey have a

significant Cronbach's alpha for items associated with the processes of the Understand, Ideate, Prototype and Implement spaces. However, for the Synthesize space, Cronbach's alpha for post-survey was lower than 0.6, which is not significant.

Table 4. Cronbach's Alpha for pre- and post-survey by space

Survey	Space	Cronbach's Alpha	Number of items
Pre	Understand	0.756	9
	Synthesize	0.58	3
	Ideate	0.684	4
	Prototype	0.854	3
	Implement	0.766	4
Post	Understand	0.754	9
	Synthesize	0.577	3
	Ideate	0.784	4
	Prototype	0.861	3
	Implement	0.729	4

To figure out the reason behind the lack of reliability of the items associated with the processes of the Synthesize space (items 10-12), we checked Item-Total Statistics. Tables 5 shows the corresponding Cronbach's alpha value when each of the items was deleted. Typically, if this value is larger than the original alpha value, the corresponding item should be deleted to increase the overall Cronbach's alpha. However, results showed that the Cronbach's alpha is lower after removing any of the items associated with the processes of the Synthesize space. Therefore, the low reliability of items associated with the processes of the Synthesize space is not because of one specific item, but all items need further adjustments.

Table 5. Item – Total Statistics

Item	Corrected Item-Total Correlation	Cronbach's alpha value when item is deleted
10	0.412	0.434
11	0.366	0.505
12	0.381	0.485

Discussion

The purpose of this research was to describe how a newly established design center at a large Midwestern University developed a survey that can be used to measure the impact of integrating HCD on students' knowledge of performing its processes in existing higher education courses. The survey was developed based on a research-based HCD taxonomy (Lawrence et al., 2021) that outlines the design spaces, the processes, and practices that define what it means for students to implement HCD within the context of a k-12 or higher education setting.

The survey was pilot tested as a pre- and post-survey with 46 students from two courses that integrated HCD in Fall 2019 semester. The overall results from paired sample t-tests indicated a significant improvement in students' knowledge of performing the HCD processes and practices. This suggests that the integration of HCD in the content of these two existing higher education courses was effective at least in providing students with opportunities to practice skills that are essential for developing 21st century mindsets such as collaboration and communication. These mindsets align with what employers of today's workforce seek in their employers. This makes teaching about and through HCD a powerful pedagogical approach that can better prepare higher education students to successfully participate in their future workspaces. Findings from our work add to empirical evidence from other studies that indicates the effectiveness of integrating HCD in higher education courses (Lake et al., 2021; Shehab et al., 2021a, Withell & Haigh, 2013).

In addition, the results indicated low reliability in items associated with the processes of only the Synthesize space. One reason behind low reliability of items associated with the Synthesize space is the poor correlation between the items. We checked the correlation of each test item with the total score test and found that all three items have correlation below 0.45. Therefore, to improve the reliability of items associated with the processes of the Synthesize space, we enriched the content of each item and we increased the number of items from three to seven. Further testing is needed to verify the increase in the reliability in items associated with the processes of the Synthesize space.

The results also indicated a relatively low construct validity. We expect that increasing reliability by changing some items associated with the processes of the Synthesize space will improve the validity of the survey. Nevertheless, one potential reason behind the low validity is that some items of the survey were broad and addressed multiple HCD practices. To address this, we revisited the HCD processes and practices as defined by the HCD taxonomy and broke down some items of the existing survey into items that are associated with specific HCD practices related to the HCD processes per space. Having more specific and targeted items is one direction for improving construct validity in future survey iterations.

Finally, the current survey analysis relied on a small sample size of only 46 responses. This small sample size could have also undermined the validity of the survey. In the future, it is necessary to collect more responses from students to ensure more accurate and stronger survey analysis.

The work presented in this paper is on the assessment of HCD which is a critical dimension that influences the effective implementation of HCD in higher education classrooms (Gómez Puente et al., 2013). Assessing students' learning outcomes as they engage in HCD experiences is a major step towards bringing HCD into K-12 and higher education classrooms (Shehab et al., 2021b). Given that surveys are self-reporting tools that may be subject to students' bias, more research is needed to test other assessment tools that can be used to measure the effectiveness of integrating HCD in existing higher education courses (Melton et al., 2012; Royalty et al., 2019). In addition, more research is needed to develop and test assessment tools that can be used to measure the impact of integrating HCD in existing higher education courses on students' understanding of the underlying disciplinary concepts associated with the course and transfer of knowledge to perform HCD processes and practices to solve other problems in new contexts.

Conclusion

In light of our analysis and suggestions, we revised our survey items. Table 6 shows the items of our revised survey. We are planning to pilot the revised survey in existing courses that integrate HCD in Fall 2021. We are aiming to pilot test the revised survey with a bigger sample size and in other higher education courses that integrate HCD. Using the collected responses, we will run validity and reliability tests to inform our progress towards developing a valid and reliable survey that can measure the impact of integrating HCD in existing higher education courses which, in turn, will promote our efforts of scaling the integration of HCD in existing higher education courses.

Table 6. The revised survey

Space	No	Item	Very Poor (not sure/don't know)	Poor	Fair	Good	Excellent
Understand	1	I know how to develop goals for the project.	1	2	3	4	5
	2	I know how to review the current landscape or context of the project.	1	2	3	4	5
	3	I know how to document my biases, assumptions, and predictions during the project.	1	2	3	4	5
	4	I know how to conduct observations that can inform my understanding of the users' needs.	1	2	3	4	5
	5	I know how to document my observations.	1	2	3	4	5
	6	I know how to run interviews with users.	1	2	3	4	5
	7	I know how to locate resources that are associated with the project.	1	2	3	4	5
	8	I know how to identify extreme users.	1	2	3	4	5
	9	I know how to reflect on my assumptions and biases.	1	2	3	4	5
	10	I know how to reflect on the projects' motivations and stakeholders' needs.	1	2	3	4	5
	11	I know how to filter content for relevance and prioritize information.	1	2	3	4	5
Synthesize	12	I know how to communicate collected data to others during the project.	1	2	3	4	5
	13	I know how to find themes and develop insights.	1	2	3	4	5
	14	I know how to identify design and research opportunities.	1	2	3	4	5
	15	I know how to define the project scope.	1	2	3	4	5
	16	I know how to build on themes and design opportunities to determine what next steps are.	1	2	3	4	5
Ideate	17	I know how to come up with ideas of potential solutions to a problem.	1	2	3	4	5
	18	I know how to communicate proposed ideas of potential solutions to others to get feedback.	1	2	3	4	5
	19	I know how to come up with alternative ideas of potential solutions.	1	2	3	4	5
	20	I know how to identify concepts that are most viable.	1	2	3	4	5
	21	I know how to develop a plan of action that outlines next steps and possible challenges.	1	2	3	4	5
Prototype	22	I know how to create a prototype.	1	2	3	4	5
	23	I know how to communicate a proposed prototype to others to get feedback.	1	2	3	4	5
	24	I know how to evaluate a prototype.	1	2	3	4	5
Implement	25	I know how to revise prototypes to build more sustainable or usable design.	1	2	3	4	5
	26	I know how to develop a plan for executing a final design.					
	27	I know how to plan for, collect, and implement user feedback to ensure successful implementation of a final design.	1	2	3	4	5
	28	I know how to monitor and evaluate social and environmental contexts to ensure the sustainability of the final design.	1	2	3	4	5
	29	I know how to execute functional iterations of a final design.	1	2	3	4	5

References

Bada, S., & Olusegun, S. (2015). Constructivism Learning Theory: A Paradigm for Teaching and Learning. *IOSR Journal of Research & Methods in Education*, *5*(6), 66–70.

Brown, T. (2008). Design Thinking. *Harvard Business Review*, *86*(6), 1–9.

Brown, T., & Katz, B. (2011). Change by Design. *Journal of Product Innovation Management*, *28*(3), 381–383. https://doi.org/10.1111/j.1540-5885.2011.00806.x

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, *8*(2), 5–21.

Ching, H. Y. (2014). Design Thinking in Classroom: An Experience with Undergrad Students of a Business Course. *Business and Management Research*, *3*(2), p110. https://doi.org/10.5430/bmr.v3n2p110

Crismond, D. P., & Adams, R. S. (2012). The Informed Design Teaching and Learning Matrix. *Journal of Engineering Education*, *101*(4), 738–797. https://doi.org/10.1002/j.2168-9830.2012.tb01127.x

Culén, A. L., & Gasparini, A. A. (2019). STEAM Education: Why Learn Design Thinking? In Z. Babaci-Wilhite (Ed.), *Promoting Language and STEAM as Human Rights in Education* (pp. 91–108). Springer Singapore. https://doi.org/10.1007/978-981-13-2880-0_6

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, *32*(6), 521–532. https://doi.org/10.1016/j.destud.2011.07.006

Goldman, S., Carroll, M. P., Kabayadondo, Z., Cavagnaro, L. B., Royalty, A. W., Roth, B., Roth, B., Kwek, S. H., & Kim, J. (2012). Assessing d.learning: Capturing the Journey of Becoming a Design Thinker. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design Thinking Research* (pp. 13–33). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-31991-4_2

Gómez Puente, S. M., van Eijck, M., & Jochems, W. (2013). Empirical Validation of Characteristics of Design-Based Learning in Higher Education. *International Journal of Engineering Education*, *29*(2), 491–503.

IDEO (Ed.). (2015). *The field guide to human-centered design: Design kit* (1st. ed). IDEO.

Jang, H. (2016). Identifying 21st Century STEM Competencies Using Workplace Data. *Journal of Science Education and Technology*, *25*(2), 284–301. https://doi.org/10.1007/s10956-015-9593-1

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design Thinking: Past, Present and Possible Futures. *Creativity and Innovation Management*, *22*(2), 121–146. https://doi.org/10.1111/caim.12023

Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H.-Y. (2015). *Design Thinking for Education*. Springer Singapore. https://doi.org/10.1007/978-981-287-444-3

Kumar, J. A., Silva, P. A., & Prelath, R. (2020). Implementing studio-based learning for design education: A study on the perception and challenges of Malaysian undergraduates. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-020-09566-1

Lake, D., Flannery, K., & Kearns, M. (2021). A Cross-Disciplines and Cross-Sector Mixed-Methods Examination of Design Thinking Practices and Outcome. *Innovative Higher Education*. https://doi.org/10.1007/s10755-020-09539-1

Lawrence, L., Shehab, S., Tissenbaum, M., Rui, T., & Hixon, T. (2021, April). Human-Centered Design taxonomy: Case study application with novice, multidisciplinary non-designers. Poster presented at *the American Educational Research Association (AERA) virtual conference*.

Lin, L., Shadiev, R., Hwang, W.-Y., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. *Thinking Skills and Creativity*, *36*, 100646. https://doi.org/10.1016/j.tsc.2020.100646

Luka, I. (2020). Design Thinking in Pedagogy. *Journal of Education Culture and Society*, *5*(2), 63–74. https://doi.org/10.15503/jecs20142.63.74

McKenney, S., & Reeves, T. (2012). *Conducting educational design research*. Routledge.

Meinel, M., Eismann, T. T., Baccarella, C. V., Fixson, S. K., & Voigt, K.-I. (2020). Does applying design thinking result in better new product concepts than a traditional innovation approach? An experimental comparison study. *European Management Journal*, S0263237320300232. https://doi.org/10.1016/j.emj.2020.02.002

Melton, R. B., Cardella, M. E., Oakes, W. C., & Zoltowski, C. B. (2012). Development of a design task to assess students' understanding of human-centered design. *2012 Frontiers in Education Conference Proceedings*, 1–6. https://doi.org/10.1109/FIE.2012.6462469

Noweski, C., Scheer, A., Büttner, N., von Thienen, J., Erdmann, J., & Meinel, C. (2012). Towards a Paradigm Shift in Education Practice: Developing Twenty-First Century Skills with Design Thinking. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design Thinking Research* (pp. 71–94). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-31991-4_5

O'Leary-Kelly, S. W., & J. Vokurka, R. (1998). The empirical assessment of construct validity. *Journal of*

Operations Management, *16*(4), 387–405. https://doi.org/10.1016/S0272-6963(98)00020-5

Pagano, A., Shehab, S., & Liebenberg, L. (2020, June). WIP: Introducing students to Human-Centered Design in a Design for Manufacturability course. In the Proceedings of *the American Society for Engineering Education Conference.* Montreal, Canada (Online).

Pande, M., & Bharathi, S. V. (2020). Theoretical foundations of design thinking – A constructivism learning approach to design thinking. *Thinking Skills and Creativity*, *36*, 100637. https://doi.org/10.1016/j.tsc.2020.100637

Panke, S. (2019). Design Thinking in Education: Perspectives, Opportunities and Challenges. *Open Education Studies*, *1*(1), 281–306. https://doi.org/10.1515/edu-2019-0022

Prinsley, R., & Baranyai, K. (2015). *STEM Skills in the Workforce: What do Employers Want? Office of the Chief Scientist Occasional Paper, Office of the Chief Scientist, Canberra*. https://doi.org/10.13140/RG.2.2.12120.60167

Razzouk, R., & Shute, V. (2012). What Is Design Thinking and Why Is It Important? *Review of Educational Research*, *82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Royalty, A. (2018). Design-based Pedagogy: Investigating an emerging approach to teaching design to non-designers. *Mechanism and Machine Theory*, *125*, 137–145. https://doi.org/10.1016/j.mechmachtheory.2017.12.014

Royalty, A., Chen, H., Roth, B., & Sheppard, S. (2019). Measuring Design Thinking Practice in Context. In C. Meinel & L. Leifer (Eds.), *Design Thinking Research* (pp. 61–73). Springer International Publishing. https://doi.org/10.1007/978-3-319-97082-0_4

Scheer, A., Noweski, C., & Meinel, C. (2012). *Transforming Constructivist Learning into Action: Design Thinking in education*. 12.

Shehab, S., Lawrence, L., Tissenbaum, M., Rui, T., & Hixon, T. (2021a, April). The impact of integrating Human-Centered Design in three higher education courses. Paper presented at *the American Educational Research Association (AERA)* virtual conference.

Shehab, S., Tissenbaum, M. ... & Sawyer, K. (2021b, June) Towards bringing Human-Centered Design to K-12 and Post-Secondary education. Symposium presented at I*nternational Society of the Learning Sciences (ISLS) Annual Meeting.*

Sjøberg, S. (2010). Constructivism and Learning. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International Encyclopedia of Education* (Vol. 5, pp. 485–490). Elsevier. https://doi.org/10.1016/B978-0-08-044894-7.00467-X

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd

von Thienen, J., Meinel, C., & Nicolai, C. (2014). How Design Thinking Tools Help To Solve Wicked Problems. In L. Leifer, H. Plattner, & C. Meinel (Eds.), *Design Thinking Research* (pp. 97–102). Springer International Publishing. https://doi.org/10.1007/978-3-319-01303-9_7

Withell, A. J., & Haigh, N. (2013). *Developing design thinking expertise in higher education*. 1–14.

Wrigley, C., & Straker, K. (2017). Design Thinking pedagogy: The Educational Design Ladder. *Innovations in Education and Teaching International*, *54*(4), 374–385. https://doi.org/10.1080/14703297.2015.1108214

Zhang, T., & Dong, H. (2008). *Human-Centered Design: An Emergent Conceptual Model*. 1–7.

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