How Engineering Educators Use Heuristics When Redesigning an Undergraduate Embedded Systems Course

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Introduction

Understanding the strategies instructional designers use in practice can help to identify the factors that influence how courses and learning environments are designed and suggest methods to improve practices. Prior research has shown that educators use heuristics, models, and frameworks[1–5], as they design their courses. Although prior work has contributed to our understanding the practices expert instructional designers use to develop new instructional materials, this work is often not based on authentic course design or redesign scenarios, describing *how* educators systematically explore problems and promising solutions in their daily work.

This paper presents a case study of the cognitive heuristics used by a cross-functional instructional design team as they modified a second-year embedded systems course for electrical, computer, and software engineering students. In this study, we conducted a qualitative analysis of 15 transcripts (over 17 hours of audio) of meetings during which the team following a collaborative instructional model for course design. Interviews, reflections, design artifacts, and informal conversations supplemented and contextualized the primary data. Through weekly meetings and course interventions, the team aimed to promote design thinking, systems thinking, professional skills such as leadership and inclusion while contextualizing course concepts and stimulating creative, socio-technical-minded development of ECE technologies for future smart systems. This instructional model shifts the paradigm from the traditional single-instructor course to a multi-designer model with multiple instructors[6–8]. Cross-functional teamwork provides an ideal setting because it features multiple actors with diverse expertise and roles, overarching departmental culture issues, and existing course material, which do not necessarily factor into the other studies.

Thus, with this study we addressed the research question:

What heuristics do a cross-functional, cross-disciplinary team of educators use when redesigning a second-year embedded systems course for electrical, computer, and software engineering students?

Literature Review

Heuristics

Taken from research in psychology, a cognitive heuristic captures a simple "rule of thumb" used to generate a quick judgment or decision[9]. Cognitive heuristics do not always offer optimal solutions, but instead serve as search algorithms or shortcut methods for best guesses that may lead to optimal solutions[10]. It is clear to some that experience is key. Riel[11] described the heuristic method as one that provides "specific experience-based guidelines" to assist in the formation of positive decisions.

Although often useful, there are cases where heuristics' use might create a disadvantage, as they introduce biases[12,13]. For example, we often rely on the representativeness heuristic[14] when we estimate the likelihood of an event by comparing it to an existing prototype in our minds, allowing us make decisions quickly. This heuristic could create a bias towards generalizing these events and create false stereotypes, such as judging a book by its cover. However, heuristics exist because people find them as an easy guide to decisions that are often "good enough" or "reliable enough"[15]. Many disciplines have identified domain-specific heuristics based on expertise, including mathematical problem-solving[16], artificial intelligence[17], user interface design[18], engineering design[19–21], and decision research[22].

Previous research on engineering design has successfully utilized the theoretical framework of cognitive heuristics to identify Design Heuristics for idea generation[19,20]. Based on evidence from empirical studies of award-winning products, protocol studies of designers, and a long-term design process analysis, 77 Design Heuristics were identified to capture the patterns of concept variation introduced during creative idea generation. An example of a design heuristic is *apply an existing mechanism in a new way*, prompting the designer to take an existing product or component and incorporate it to function differently in the final outcome. In another study with engineering students, protocols revealed multiple cognitive heuristics used to structure and frame the presented problem in alternative ways[21]. For example, the heuristic *incorporate additional scenarios* was demonstrated by a student defining the problem as, 'providing electricity whenever and wherever electricity is not available'. This empirical evidence was collected through content analysis, and cognitive processes of experts, as heuristics are based on collected past experiences and difficult to verbalize.

Heuristics in instructional design

From an instructional and curriculum design perspective, the use of heuristics can prove valuable as behavioral research shows that experts utilize heuristics effectively, which distinguishes them from novices[23]. Evidence suggests that expert instructional designers use heuristics when designing new or revising instructional systems[5,24,25]. A Delphi study conducted by York and Ertmer[5] examined previous think-aloud findings[24], and resulted in 62 key heuristics articulated as potential directions for instructional change in instructional settings for organizations. An example of an instructional heuristic in this study is *negotiate the scope of the project with the client and create a statement of work upfront*, emphasizing the importance of consensus about the expectations of the work ahead of its implementation. However, determining which heuristics were actually used in practice was beyond the scope of this study.

Other studies of instructional design practices show common approaches, with varying research methods across a variety of settings and in a variety of instructional design tasks. Visscher-Voerman[26] extracted 16 principles demonstrated by instructional designers through retrospective interviews. Kirschner and colleagues[27] compared university and business instructional designers through a Delphi-like study (using Visscher-Voerman's 16 principles) and a short team design task. In another study, Perez and colleagues[28] compared expert and novice instructional design processes using a think-aloud protocol in laboratory setting. Although these studies do not report on their findings as heuristics, they all rely on data collected from expert practices and demonstrate several similarities, including an emphasis on learner and context analysis, the application of proven techniques, and problem framing. However, these studies also show important differences between contexts (e.g., university and business instructional design settings[27]).

In this paper, we apply the theoretical framework of cognitive heuristics to the process of identifying commonly used instructional heuristics in an engineering education setting. Further, we build on prior studies by exploring heuristics in an authentic course design task. How do expert educators use cognitive heuristics in course design? How do they explore and refine educational content, student engagement, and assessment techniques? Examining how educators transform their existing, established courses to facilitate new approaches may lead to the discovery of novel methods for curriculum advancement. The identified heuristics can then be introduced to novice educators (or experts who are looking for new ways to explore alternative strategies for course redesign) as a support tool as they develop and revise courses.

Methods

Setting and Participants

The setting of this study was a second-year embedded systems course meant for electrical, computer, and software engineering students at a large university in the midwestern United States. A team of nine educators (Table 1) formed an x-team (a cross-functional, collaborative team with diverse expertise) to make revisions to the course over each of the next four semesters. The team formed and met 2-3 times per week during the summer before the first course iteration. The team then continued to meet about once per week during the Fall 2017 semester, from which data for this study was collected.

Data Collection

Previous studies have found heuristic use to be implicit, such that the person is not consciously aware of its use[1,19]. Thus, data collection methods often focus observational data (e.g., think-alouds) and concrete artifacts (e.g., journals, design concepts) that demonstrate heuristics without explicit verbalization from participants. In this study, we collected a variety of data to explore heuristics from multiple lenses. These data include audio recordings and written notes from team meetings on instructional design of the course, design artifacts (including final course materials), interviews with team members and course instructors, and semi-weekly reflections from the course instructor.

Meeting recordings and the resulting transcripts provided the primary source of data. Meetings lasted 1–2 hours and featured discussion of the course to be redesigned, negotiation of course content, planning assessments and pedagogy, and collaborative decision-making and artifact building. While not every team member participated in each meeting, at least three team members participated in all meetings. We focused on meetings during the month preceding and the month and a half after the beginning of the semester due the heavier focus on planning and design of the course (later meetings tended to discuss logistics of implementation and feedback on planned activities). In total, we analyzed 15 meeting transcripts from 17.6 hours of audio, plus detailed notes from an additional 6 meetings that were not audio-recorded. Interviews, reflections, design artifacts, and informal conversations supplemented the primary data by providing context for the observed heuristics and demonstrating the eventual outcomes of heuristics.

Table 1. Study participants

Pseudonym	Position	Department	Area(s) of Expertise
Michael	Associate professor	Electrical and computer engineering	Previous and current course instructor; embedded systems
Sydney	Full professor	Electrical and computer engineering	Previous course instructor, embedded systems
Freddie	Associate professor	Industrial design; electrical and computer engineering	Engineering education; reflection
Beth	Associate professor	Industrial design	Design thinking; engineering education
Stanley	Assistant professor	Aeronautical engineering	Engineering education; reflection; professional formation
Leo	Postdoctoral research associate	Industrial design; electrical and computer engineering	Engineering education; design thinking; innovation
Rebecca	Postdoctoral research associate	Education	Higher education; identity formation; reflection
Jonathan	Teaching assistant	Electrical and computer engineering	Previous and current teaching assistant; student experience
Andy	Research assistant	Industrial design	Design thinking; student experience

Data Analysis

During this study, we employed an iterative thematic analysis approach[29] to identify the heuristics used by the educators and larger categories of heuristics that might emerge. This approach was inductive, rather than relying on extant coding schemes. While heuristics have been well-documented in many disciplines such as psychology, industrial design and engineering disciplines, and to some extent in instructional design, in this study, design objects (e.g., course structure, content, activities, etc.), setting, and participants are substantively different than in previous heuristics studies. Relying on an inductive approach for data analysis allowed us to begin exploring heuristics in this setting before drawing connections to others.

We began analysis by creating an operational definition of a heuristic to guide open coding. Three researchers with engineering education expertise each read through the data set and reconvened to further discuss excerpts from the data, the operational definition of a heuristic, and the mutual suitability between the operational definition and the data. The team agreed to focus on the meeting data and use additional data as a supplement (e.g., to explore the materials derived from heuristics evidenced during meetings, or to explain why a participant used a specific heuristic).

The researchers then began to independently code portions of the data to identify potential heuristics. Meetings before and towards the beginning of the semester (July - September) were prioritized because they featured the most ideation and decision-making. Then, consistent with previous heuristics studies[19,20], the researchers convened regularly to discuss the potential heuristics, review the data, refine heuristics, create larger categories of heuristics, and, eventually, agree upon a final set of heuristics, with detailed definitions and case examples. We report these heuristics in the following section.

Results

Our analysis showed evidence of frequent heuristic use within the x-team. A set of 22 instructional heuristics (Figure 1) emerged from the data describing how educators explore and iterate upon the problems and solutions in course design. These heuristics are grouped into six categories, based on the distinct purposes for which they were used during the course redesign process (Table 2). In the following sections, we present the heuristics within each category and provide a deeper review of select heuristics.

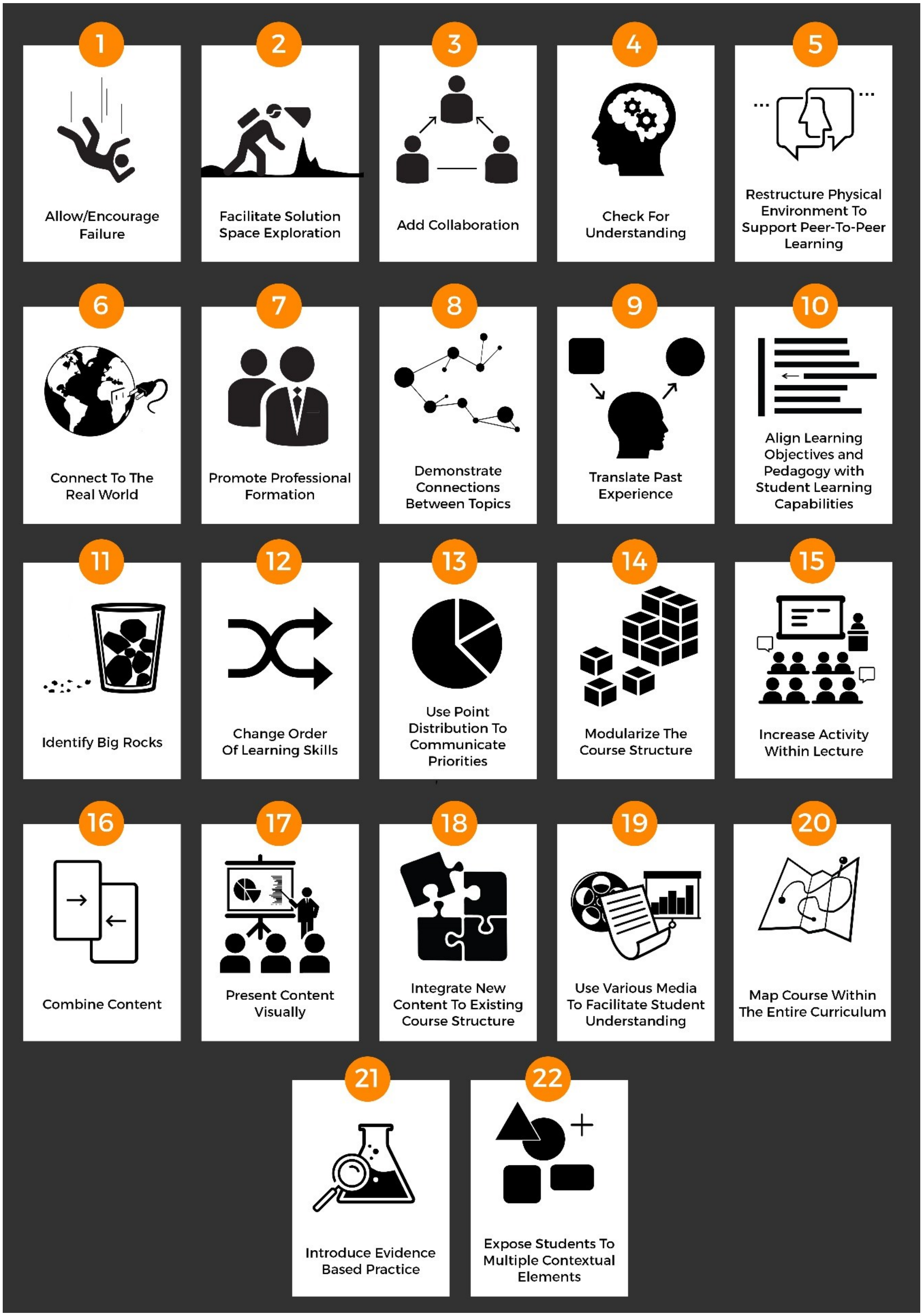

Figure 1. Visualizations of the 22 heuristics

Table 2. List of heuristics by category

Category	**Description**	**Heuristics**
Determine content and implementation	These heuristics are used to select and refine course content and the order and detail in which it is presented in the course	- Identify the "big rocks" - Map course within the entire curriculum - Modularize the course structure - Combine content - Integrate new content to existing course structure - Change order of learning skills - Align learning objectives and pedagogy with student learning capabilities
Contextualize course content	These heuristics are used to situate course content within a larger professional engineering ecosystem	- Connect to the real world - Promote professional formation - Expose students to multiple contextual elements - Demonstrate connections between topics
Promote student engagement	These heuristics are used to facilitate more pronounced and sustained involvement between students and the course ecosystem	- Add Collaboration - Restructure physical environment - Increase activity within lecture - Check for understanding
Communicate course content	These heuristics are used to provide new ways of presenting content to students	- Present content visually - Use various media to facilitate student understanding - Use point distribution to communicate priorities
Introduce new mindsets	These heuristics are used to promote new ways of thinking among students as they engage with course topics	- Allow failure - Facilitate solution space exploration
Use prior art	These heuristics involve participants relying on prior art and past experiences to support team objectives	- Translate past experiences - Introduce evidence-based practices

Determine Content and Implementation

Seven heuristics comprised this category, which focused activities on selecting, refining, and organizing course content and placing it within the course (Table 3).

Table 3. List of heuristics related to determining content and implementation

Heuristic	**Description**	**Example**
Identify big rocks	Focus on larger, key topic areas when selecting course content rather than focusing on specific techniques and skills students should learn	The team discussed ways in which the hierarchy of course content would communicate important information and effectively relate it to real world implications.
Map course within the entire curriculum	Identify how the course connects to other courses to build a learning progression and use this placement to select appropriate course content	The team identified the prerequisite and follow-up courses taken by students. They selected and refined course topics and activities to align those addressed by follow-up courses.
Modularize the course structure	Organize the course topics into distinct modules that can be easily reorganized, added, or removed without disrupting other modules	Create one- or two-week modules focused on distinct topic areas that each feature formative quizzes, reflections, lab exercises, and team-based activities in lecture.
Combine content	Merge/synthesize two or more topics to promote efficiency	Develop a model of design thinking in the technical domain by exploring connections between the processes and mindsets of design thinking and technical engineering design
Integrate new content to existing course structure	Use an extant activity or environment within the course to teach a new topic	The team added design thinking activities (new content) to existing laboratory exercises
Change order of learning skills	Reorganizing the timeline in which concepts and skills are taught in the course	The team reorganized course content to accommodate in-class design thinking activities
Align learning objectives and pedagogy with student learning capabilities	Simplify or advance content and activities based on understanding of student preparation for those topics and activities	The team recognized that students entered the course with a limited conceptual understanding of time and frequency

The *integrate new content to existing course structure* heuristic represented an attempt to situate a new topic within an existing course. As the meeting excerpt below demonstrates, this heuristic originated as an attempt to add desired content to a course without removing any of the desired existing content or increasing the workload of students. The team approached this by adding the content through new activities that connected to the activities students were already completing in the laboratory portion of the course. By integrating new content to existing content and activities, the team also found a way to present both topics to students in a connected and more immersive way.

Leo: I like the point that Freddie brought up is we can't just keep adding things and then not necessarily taking them out. I was also thinking if we had any way in making things serve multiple purposes in a meaningful way. But yeah, the more we add, the more we—

Sydney: And I do that too. Sometimes if you are teaching teamwork, it's not because you said, "Here's a lecture on teamwork," you know, or, "Here's an activity dedicated to teamwork." It might mean that you share some information about teamwork, but mostly, it's students learning it through the process of learning. Right? So, the activities you have in class are you're asking them to do those activities ... Those are set up to promote good teamwork skills, for example. And that's how I see some things being integrated is you learn some skills not by what you are teaching, but by how you're teaching or how they are learning the other skills. To me, that's a nice integration. And then sometimes it's just making it explicit to the students. So, the students realize, "Why are you doing this?" Well, you're learning multiple things through this activity here.

Leo: I mean that's kind of the thing I was hoping we could do with design thinking in the lab. It's just one of those things where we didn't identify that yet of how to integrate it without changing it too much.

Sydney: That's a fair point. Yeah. So, I'm definitely a proponent of that. It may be that as we go through our design thinking, you know the initial way we try to add something is something separate. Right, because it's something we can think about. But then, before we actually say, "Well, let's do this." It might be, "Well, how can we accomplish that same thing in a more integrated way, right? How could we change some element of the lab itself to add that in or just structure something so that students are learning the same thing."

Leo: Yeah, and I mean it's a challenge because with a lot of the aspects of design thinking are related, so you kind of need, well, you don't need, but it's harder without the context of other things. So, if you are doing, like an ideation thing, yeah, you can try to come up with a lot of different ideas and a great variety of influence and all that. But it's not as meaningful if it doesn't have the context for which you are designing, and you don't get that. So, if you're de-contextualizing, and doing idea generation, it's not as easy. Or it's not as strong without those things. I don't know. I think I tried to come up with some ideas for the lab, but it was all, it seemed kind of tacked on. I do think this approach is interesting with the pre-lab and the post-lab questions, as long as they are—

Sydney: Well, and that was something that you had actually ... You know you had started to do that right? That's how we started to walk through it. And I do think that that was kind of a straightforward simple way to think about getting design thinking going. And it wouldn't have required a lot of in-depth understanding from the instructor at that point right? The instructor still gets to do what the instructor wants in that layout. And it might be that you can add it and it might add it fairly simply without a lot of additional work for the students. But, like I said, I don't mind integrating it

The application of this heuristic led to a series of activities within lab during which students were guided through design thinking process stages of empathize, define, ideate, prototype, and test. Students created deliverables within this process each week that resulted in an "application story" that students used to guide and integrate design thinking to their final lab project.

Contextualize course content

Heuristics in this category focused on making course content more meaningful and applicable to students by situating topics within broader professional and sociotechnical contexts (Table 4).

Table 4. Heuristics used to contextualize course content

Heuristic	Description	Example
Connect to the real world	Present content through activities that link it to applications in the real world	Introduce an activity in which students identify and reflect upon a news story or research paper demonstrating an application of an embedded system
Promote professional formation	Introduce or modify activities in the course to facilitate professional skills and mindsets	Using a research-based professional identity formation framework to guide reflection activities within the course
Expose students to multiple contextual elements	When covering content, introduce it within relevant systems and/or socio-technical contexts.	Instead of covering the hardware in isolation, discuss it in connection with other components, the overall role it plays in the system, and its historical development.
Demonstrate connections between topics	Present course content in a way the makes explicit for students the connections to other content in the course	Develop a course roadmap (i.e., flowchart) that shows the distinct topics in the course and how they interact and inform each other.

The *promote professional formation* heuristic represented an attempt to build professional formation into the course, either through targeted activities or modifications of technical activities. One way the team used this heuristic was by using professional formation frameworks to structure class activities. For example, the team utilized Ibarra's[30] model of professional identity formation that had previously been operationalized in an engineering education context to better understand student sense-making through portfolio development[31]. Below is an excerpt of the team recognizing the need for a specific professional formation activity. They worked to identify elements of an existing design project that connected to aspects of professional formation within Ibarra's model (i.e., engagement in professional activities and sense-making), and propose modifications that could support further professional formation. The group eventually decided to pair the course's final design project with a reflection activity to ensure sense-making on professional activities.

Michael:	So, the question would be, what type of activities do we have planned to help them find their place in this discipline? And currently we don't have any. A true statement, that's a true statement.
Sydney:	So, I mean, could they—I think the project is. So, the project is sense making, right? It's helping them to bring together what were disparate, possibly disparate ideas from throughout the semester, bring them together into a real application that's solving some particular, solving a problem. So, they kind of put, they're having to do synthesis ...
Michael:	Yeah, I think it can be. I think, and perhaps it does, but maybe we'll do it a more structured way if we had something like a reflection...
Sydney:	I agree, but it just, I think projects are a good sense making type thing, but now I think—
Michael:	A good opportunity for them to have that. Yeah.
Leo:	So, I was going to say, I think the project is the engagement in professional activities, and then the sense-making is where they're making sense on the project. So, I think you do need that reflection.

Promote Student Engagement

Four heuristics comprised this category, which focused on pedagogical techniques that were intended to help or inspire students to more actively interact with the course content, the course environment, and with each other (Table 5).

Many of the early discussions among the team focused on adding collaboration to the course to promote social learning and increase student engagement and activity throughout the course (using the heuristic *add collaboration*). While collaboration was already built into the course laboratory exercises, collaboration was added to both lectures and homework. In lecture, for example, the team added collaboration through a jigsaw activity. As the team evidenced below, this activity was meant to support collaboration, but also to use that collaboration to help students manage the complexity of data sheets, an important course topic.

Table 5. Heuristics related to promoting student engagement

Heuristic	**Description**	**Example**
Add collaboration	Convert an individual activity into a team-based activity	Allow students to complete homework in groups
Restructure physical environment	Rearrange the layout or organization of the classroom and/or laboratory to alter student interaction	Rotate the lab benches to face each other rather than the whiteboard to reorient students' sightlines to other teams and create a more social space in lab.
Increase activity within lecture	Add hands-on, collaborative, and reflective activities to lectures	Introduce a jigsaw activity during a lecture focused on the datasheet associated with the course's primary hardware platform
Check for understanding	Find a way to gauge how well the class understands a concept or topic	Use short, formative quizzes to determine how well the class understand a current topic and use the results to realign future courses

Leo: One of the reasons for putting the jigsaw, also for this one, it's supposed to get them engaged in the datasheets. The hope is that jigsaw gets them to a comfortable start of using the datasheet, hopefully that will then propel them towards the ...

Sydney: So, you're hoping that this would just be a learning exercise in itself that then they'll kind of do on their own maybe.

Leo: Yeah, so, they can get, really get a hands-on feeling that that structure of working with a group.

[...]

Michael: So, the jigsaw, we'll look into that, in the sense that, they'll get experience on how to work in a team to learn how to use a bigger system. Jigsaw is going to be an opportunity to kind of, if we word it properly, let them know okay, some professionals that exist is trying to help their team understand a large system, a complicated system.

Communicate course content

Three heuristics comprised this category, which focused on altering how course content and learning objectives were communicated to students, especially to promote more engagement and understanding among all students (Table 6).

Table 6. Heuristics related to communicating course content

Heuristic	**Description**	**Example**
Present content visually	Revise or expand presentation of course topics from text-based to visual presentation.	Create posters of important course topics and content to hang in the lab space.
Use various media to facilitate student understanding	Expand presentation of lecture material to additional media forms (beyond verbal and slideshow presentation)	Create videos, diagrams, and posters to supplement traditional lecture materials.
Use point distribution to communicate priorities	Apply higher grade weights to more important aspects of the course	Introduce a participation grade to demonstrate engagement, reflection, and collaboration as important learning topics within the course.

The heuristic *present content visually* represented an attempt to demonstrate an alternative to the text-based format in which information was often presented. Throughout the meetings the team often discussed creating posters for the lab space that presented important topics in the course (e.g., a systems-level diagram of the primary course hardware platform, a process model of design thinking). These posters were intended to demonstrate an alternative visual perspective, but were also planned to offer frequent reminders and quick references for students.

Introduce New Mindsets

Two heuristics comprised this category, which focused on facilitating an environment where students are encouraged to make mistakes and avoid constraining their ideas and approaches (Table 7). This would allow students to experience a non-linear process and explore several different solutions rather than one that simply worked. Exploration of similar heuristics in different settings would likely focus on different mindsets.

Table 7. Heuristics related to introducing new mindsets

Heuristic	Description	Example
Allow/Encourage failure	Allow students to make mistakes to encourage familiarity with anon-linear process and the ambiguity associated with it.	The team utilized peer-to-peer learning practices to allow students to understand their answers weren't as optimal as others.
Facilitate solution space exploration	Encourage students to recognize the importance of generating multiple solutions through experimentation.	During a design thinking workshop, students were given a problem in which they were asked to explore many possible solutions, rather than one that worked.

In the following excerpt, Sydney describes a priority of helping the students learn from failure and proposes a method to support such learning. In this case, the failure is lower stakes, e.g., demonstrating an answer that is not as strong as another team's answer. The team also discussed, but did not implement higher stakes learning from failure, e.g., failed design project outcomes.

> I am very interested also on some of the learning from failure. I don't know how but the learning from failure, the only thing I can say is from the team-based learning, you know, students will come up with answers that have flaws in them. Then they do learn and they see other students answers in a way that their reported out. So, students can learn from failure a little bit because their answer wasn't maybe as optimal as some other group's answer.

Use prior art

Two heuristics comprised this category, which focused on applying previously developed solutions into the current course design environment (Table 8). Often, these heuristics were paired with or inspired heuristics described above.

Table 8. Heuristics related to using prior art

Heuristic	Description	Example
Translate past experiences	Consider an approach taken in a previous course that you taught, designed, or experienced as a student.	Apply the approach to student reflection one instructor used in other electrical and computer engineering courses
Introduce evidence-based practice	Apply an approach with documented evidence of success in other learning environments (e.g., research papers)	Use team-based learning to structure collaboration in the course and learning activities/assessments in lectures

The following excerpt demonstrates Sydney (a previous instructor of the course) discussing how she allowed collaboration on homework. This utilization supported efforts initiated by another heuristic (*add collaboration*) by provided a concrete example of how it could be implemented in practice and benefits it could provide.

> I did this in my undergrad, in a class like this at the earlier undergrad, was letting them work with others, but if they're working with others and any of their answers are going to be at all similar, they have to put the other person's name on there. They have to give credit. It actually, the honest students then are going to list that other person's name. You go check it. If the other person doesn't list that, that they were, that's a way that you go talk to that student then about academic honesty, dishonesty and how this relates to the whole, it's a learning opportunity for these other students. Maybe you give them a warning then.

> Often if I will note on the first homework, wow, you know, some of them are acknowledging they worked with others, some aren't, I can tell they have and none of them has acknowledged or one acknowledged, then I kind of use that as a warning, this is your warning, and then I guess I haven't always policed it, like my job is to catch everybody. But I want them to understand that you're doing work with others, actually that's good, collaboration is good. But you still need to give others credit if they worked on things with you and then you also need to know you're accountable for the work as well… Plus it's helpful to know which students are working with other students and which are not. In some cases I think you can help some students by saying, especially the students not doing very well on the homework, you know, have you thought about getting into a study group with some other students? Other students are doing this and you're kind of leveling the playing field for some of those students who might not be. It's a balancing act certainly.

The course instructor, Michael, was initially uncomfortable with this change, but the prior successful use supported some buy-in. However, he did begin to modify the previously-used approach to better align with his vision for the course, more specifically to still "have people get rewarded for putting the time to do homeworks that are very challenging."

> I'm definitely up for experimentation with that, especially if I was to take five points out of [the homework grade] and put it towards kind of group, in-class work. I think by doing that, that also doesn't hurt the students that are actually doing their individual work. Those are students that typically come to class, so they'll still be getting that five percent.

Discussion

The primary goal of this study was to investigate how a cross-disciplinary team of educators explored problems and proposed solutions when redesigning an undergraduate engineering course. To meet this objective, a rigorous qualitative methodology based on best practices in inductive analysis[29] and heuristics research[19–21] was followed. We identified patterns of strategies discussed from a variety of data sources, including meeting transcripts, course materials, and team member interviews and reflections. The analysis identified 22 heuristics occurring at least twice in the 15 meetings analyzed. These instructional heuristics varied in that some identified means to promote student engagement and introduce new mindsets, while other explored desired course content, objectives, and outcomes. As expected, multiple heuristics were identified in individual conversation clusters, suggesting the frequent exploration by educators from both the student perspective and the educator perspective. Although educators in these meetings had different disciplinary and instructional design experiences and practices, the prevalence of observed heuristics in the data suggests their potential importance in curriculum design regardless of the discipline.

Explorations of what specific skills students should be learning, mindsets they should be practicing, and the strategies for their engagement, and the alignment of these with the technical course content, has long been identified as an important stage in the instructional design process[31–33]. However, little information is available about how educators successfully accomplish these goals. The observed heuristics each capture just one transformation to identifying a challenge in a classroom setting (i.e. *identify big rocks*) or a solution to the problem (i.e. *connect to the real world*). Each heuristic helps the educator by providing additional structure and specifies new goals towards a new exploration[35]. Those with more experience with these heuristics may be more adept at exploring alternative means to deliver the content or identify the true needs of the students in the classrooms, resulting in more innovative teaching practices. The heuristics identified in this study can be applied to a variety of scenarios for teaching and learning experiences. For example, the heuristic, *expose students to multiple contextual elements* might trigger educators to integrate a visit to the sites where the solution would be used, assign the students to identify the individual components of a system and their relationship to each other, or define the role and impact of alternative solutions for the same problem in different cultures.

Perhaps counterintuitively, the heuristics identified in this study suggest that educators often rely on their own personal experiences that narrow their perspective in planning and guiding the learning experiences and the intended learning outcomes. This is consistent with previous findings in instructional design[25,28]. Following York and Ertmer's findings[5,24,25], our study participants did not use any heuristics that related directly to instructional design models. They seemed to focus more on the practice and immediate application, rather than relying on the mental models of practice[24].

The results of this study offer empirical evidence of the presence of instructional heuristics in cross-disciplinary educational conversations. Some of the extracted heuristics show similarities to previously identified heuristics. Using the heuristics identified by York and Ertmer[24], "Use previous experiences, if possible, as a starting point for", could lead to similar outcomes with *Translate past experiences*. "When designing instruction, consider active learning. Ask yourself, 'How can I make learners more actively engaged'" likely corresponds to the promote student engagement category, with heuristics including, *add collaboration*, *restructure physical environment*, and *check for understanding*. However, the identified heuristics offer more explicit guidelines for *how* to achieve each objective. For example, York and Ertmer's suggested heuristic, students' active engagement (active learning), could be achieved through peer-to-peer learning, jigsaw approach, anonymous questions, using movement and more.

In contrast to previous approaches, heuristics extracted in this study provide clear directions on *how* to accomplish a certain goal in addition to the fact that they were actually used in practice. The compilation of many rich meeting discussions from a cross-disciplinary instructional design team provides a strong empirical basis for conclusions about how educators across disciplines actively explore new ways to explore problems and solutions in educational practices. For example, the heuristic, *align learning objectives and pedagogy with student learning capabilities*, urges the educator to build empathy with the students to understand their struggles with certain content and adjusting the content to meet the needs and capabilities of the students. By making empirical evidence of how educators have explored alternative approaches in curriculum design, the results identify specific commonalities that may help other educators explore problems and solutions as they develop courses. Additionally, these heuristics reflect the underlying ontology of the instructional design domain because they include the exploration methods that educators find useful rather than a logical model or exhaustive set of possible methods.

Limitations

While the qualitative inductive analysis method allowed us to identify and describe heuristics in curriculum design, our outcomes do not speak to causal determination, prediction, or prescription of a successful or good curriculum design. Assessment of course teaching outcomes and student reflections of learning practices are outside of the scope of this study. However, the goal of this study is transferability to create thick description in order to let others make connections to their own situational contexts[36]. This study is a case of practice in instructional design. Data was collected *in-situ*, without any prompts of heuristics; however, it describes one cross-disciplinary team's efforts in curriculum design, for one particular engineering course. Qualitative case studies with small sample sizes (such as ours) do not claim generalizability. Instead, the details provide grounding for transferability to other contexts[37]. One limitation of the study was that we were not able to assess the impact or quality of each heuristic and how their implications varied and whether there were some favored more over others in application scenarios. Most of the team's conversations reflected ideas to follow through or clarification that led to new areas of exploration. However, we have not thoroughly analyzed which of these ideas were executed and, if they were, how they altered student experience or learning practices. Future research is needed to understand how these heuristics vary across other disciplinary educational practices, and also to test these heuristics' efficacy as prompts to encourage educators to consider alternative perspectives in curriculum design. Further, it is important to demonstrate a direct link from instructional heuristics to student learning practices.

Implications

The results of the present study add to instructional design methods, models and heuristics by identifying specific ways in which educators appear to alter their approaches in order to arrive at discovered alternatives, and consequent solutions. The documentation of the heuristics offers an account of how educators approach a curriculum design, *in-situ*, and transform it into distinct, restructured versions to solve. Instructional heuristics may be useful in professional training of educators at many levels, to better prepare them for curriculum design. Faculty in research organizations, in particular, are trained in conducting research rather than designing curriculum. This set of heuristics may help them understand the variety of potential ways to achieve certain learning objectives. By using the instructional heuristics, a novice (or expert) educator can choose a heuristic, apply it to the current curriculum, and see where the resulting transformation to the course leads. Exposure to a variety of heuristics, and experiences in applying them to many different educational contexts, may lead to the development of expertise in curriculum design and innovation.

Conclusions

The goal of this study was to identify a set of instructional heuristics from the discussions of a cross-disciplinary team and interviews of the course instructors through curriculum design and development practices. This empirical study suggests there are specific heuristics for finding a problem and transforming it into a set of alternative solutions or approaches to take. These heuristics capture alternative perspectives that may lead to more varied and innovative curriculum design strategies. These results identify specific ways educators discover challenges and provide needed content knowledge for implementing potential solutions for them. The results also suggest ways for developing tools for educators of various levels in improving their teaching practices, potentially leading to more creative course and curriculum design.

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