Ethical Reasoning in First-Year Engineering Design

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Abstract

Purpose. Ethics is too-often relegated to a stand-alone course taken late in engineering programs, rather than effectively integrated into core coursework [1, 2]. Faculty sometimes have concerns that such integration will be challenging for students to manage or might distract them from core content. However, ethics-across-the-curriculum helps students understand the link between the engineering work and its positive and negative impacts and also see ethical considerations as part of engineering, rather than an add-on [2, 3]. In this study, therefore, we investigated opportunities for integration of ethics education into design challenges.

Methodology. We collected data in a first-year, 1-credit chemical engineering course that included an entrepreneurial design challenge (OPE challenge) and a community-based design challenge (AMD challenge). Both challenges culminated in short, video-recorded team pitches of their design solutions. We conducted qualitative analysis, coding the videos from five semesters (N= 69 four- to five-member teams). Specifically, we attended to ethical reasoning (nonmaleficence, beneficence, stakeholder agency and just distribution of risks and benefits). We compared the design challenges in terms of the kinds of ethical considerations students made using a two-tailed sign test.

Results. In both challenges, students considered multiple points of view and described the benefits of their design solutions. Few students considered nonmaleficence. Some students provided detailed perspectives of needs or benefits for those from marginalized or vulnerable populations (children with special needs, elderly, members of Navajo Nation). In the acid mine drainage challenge, a few teams proposed expensive solutions and warranted these costs by emphasizing the harm to people and planet. Most teams proposed feasible solutions and considered specific community concerns. We found that the entrepreneurial challenge prompted significantly more teams to use beneficence in their arguments, $z = 3.92, p < .001$.

Conclusions and Implications. Our results demonstrate that even with limited prompting to do so, a realistic design challenge can support students to employ ethical reasoning. We found that few students considered nonmaleficence, suggesting the need for scaffolding. Likewise, although some students provided considered accounts of the needs of marginalized or vulnerable populations, specific scaffolding could better support this.

Introduction & research purpose

Ethics is too-often relegated to a stand-alone module or course taken late in engineering programs, rather than effectively integrated into core coursework [1, 2]. Faculty sometimes have concerns that such integration will be challenging for students to manage or might distract them from core content. There is a lack of consensus about what effective engineering ethics education should entail [4]. Compounding this, many faculty “believe that engineering design is an ethically neutral task” [5], are not sufficiently prepared to support students to consider ethics, and commonly view ethics as belonging late in engineering programs [2, 10]. In part because of the technical focus of degrees, both faculty and students tend to undervalue the more emotional aspects of engineering work, such as showing *care* about stakeholders [2].

In this study, we investigated how realistic design challenges might prompt students enrolled in a 1-credit, first year chemical engineering course to use ethical reasoning. We build on past work that frames ethical reasoning as comprising four principles [6]; these fall along two axes: harm (nonmaleficence) versus benefit (beneficence) and individual (stakeholder agency) versus collective impact (just distribution of risks and benefits).

Literature review

Common approaches to engineering ethics education

When ABET began requiring outcomes tied to ethics, a common approach taken by many programs was to add a standalone experience, either as a course or module. Modules commonly include case studies [7], many of which are somewhat contrived versions of authentic problems, scaffolded to ensure the ethical issues are salient to students [8]. Using such cases, first year students can reason through the risks and benefits of engineering-related work [9]. There are various ways students are supported to engage with cases; one of the more effective approaches involves asking students to role play or place themselves into the case scenario and explain how they would have responded [10, 11].

While such activities are commonplace, others have argued that case study is insufficient because of its backward-facing nature, making it challenging to consider future concerns connected to emergent technologies and needs [12]. One way to address this concern is to use a phased approach beginning with cases, followed by integrated ethics tasks, and culminating in a full course [13]. Increasingly, engineering programs are seeking ways to integrate ethics through the curriculum [14, 15] or in tandem with service learning programs [16, 17]. Service learning approaches, in particular, seem to help students to view ethics as central to engineering [17]. Ethics-across-the-curriculum helps students understand the link between engineering work and its positive and negative impacts, and in turn see ethical considerations in tandem with engineering, rather than as an add-on [1-3].

Design as a setting for understanding ethics

Researchers have previously proposed that ethics can be brought up *naturally* within the curriculum [13], in contrast to contrived cases. As design is increasingly incorporated into first-year and core engineering courses, these offer an opportunity to efficiently thread ethics education throughout the curriculum [5]. Research on students participating in a service learning design project showed that they used ethical reasoning throughout their design process [17]. For instance, as they framed the design problem, they considered benefits to stakeholders, stakeholder agency, and how their design would be accessible to all stakeholders. As they worked with actual stakeholders, they became more sophisticated in their ethical reasoning. This suggests that students have the capacity to *care* or *empathize* with stakeholder needs. Care is a key mechanism for understanding problems and addressing them from stakeholder points of view [3, 13]. Empathy refers to the ability to consider other perspectives and experiences [18-22].

When considered with the principles of ethical reasoning, inclusivity also matters when considering caring about stakeholder points of view. While it may be relatively easy for a designer to consider perspectives they are familiar with, it is more challenging to empathize with those they are less aware of. In order for risks and benefits to be justly distributed [6], however, it is important to consider the perspectives of vulnerable and marginalized populations. In recent years, there has been an increase in recognition of inclusivity as part of ethical engineering. For instance, in 2017, the *Statement of Ethical Principles* developed by the Engineering Council and the Royal Academy of Engineering in UK included the requirement of promotion of equality, diversity and inclusion under the broader principle of Leadership and Communication [23]. Likewise, the code of ethics developed by American Society for Civil Engineers, updated in July 2017, includes that engineers are responsibility for considering the inclusion of diverse perspectives in the communities they serve [24].

Environmental ethics and justice

While there has been some debate about whether sustainability should be included in engineering ethics [25], many have articulated links between ethics and environmental concerns [8, 26]. Impacts on the environment can be viewed through three of the four principles—nonmaleficence, beneficence, and just distribution of risks and benefits [6]. While some faculty feel concern that the complexity of sustainability and environmental ethics may overwhelm students, researchers have successfully supported even first year students to understand why these are relevant for engineers [27]. Approaches that incorporate environmental ethics into engineering can provide a more holistic and sophisticated understanding of ethics and sustainability [28]. Just distribution of risks and benefits is particularly relevant, considering that environmental disasters can have compounded effects on marginalized and vulnerable populations [11, 29]; students need opportunities to consider these in tandem [28]. We argue that design challenges can provide an excellent opportunity to do this.

Methodology

Research questions & design

In this study, we investigated opportunities for integration of ethics education into design challenges. We used design-based research [30, 31], the hallmark method of the learning sciences; following this approach, we iteratively tested our "humble" learning theory under real-world conditions [32]. Specifically, we sought to investigate how design challenges that are contextual, current, relevant, and reflective of professional practice can support students to engage in ethical reasoning by being scaffolded to consider diverse stakeholder needs. The design challenges were not client driven, but were specifically developed to have an authentic feel and clear stakeholders. To guide our investigation, we posed the following questions:

1. What kinds of ethical reasoning do students demonstrate in their final project pitches?
2. Do the kinds of ethical reasoning vary by design challenge type (community-focused versus entrepreneurial)?

Setting, participants & materials

Participants included student teams of four to five students enrolled in five semesters of an introductory 1-credit chemical engineering course at a Hispanic-serving, very high research university in the Southwestern US. Teams were formed by the instructors. Starting with the second semester, the instructors used CATME software [33], emphasizing similar schedules, ensuring every team had a student with experience using presentation software, and not isolating minority students. A high percentage of students work or care for someone, making common schedule availability a priority.

Beginning in the 2016-2017 academic year, we redesigned the introductory course to focus on design challenges. Each semester, we refined the challenges based on student feedback and performance. Students complete a sequence of assignments (Table 1). We developed these intentionally to be relevant to students' lives and build upon their everyday and cultural experiences [34-37]. For instance, the OPE challenge asks them to propose an application of an antimicrobial material building on their everyday experiences, and the AMD challenge builds on regional knowledge of the 2015 Gold King Mine spill. In this study, we focus on the OPE entrepreneurial design challenge and acid mine drainage community-focused design challenge, detailed below.

Table 1. Assignments across each iteration of the introductory course

<table>
<tr><th></th><th>Engineering identity letter</th><th>OPE entrepreneurial design challenge</th><th>Evaporative cooling (EC) design challenge</th><th>Acid mine drainage (AMD) community focused design challenge</th><th>Why Chem E challenge</th></tr>
<tr><td>Fall 2016</td><td rowspan="5">Students write a letter about ways their past has prepared them to become an engineer</td><td rowspan="5">Students propose entrepreneurial uses of an antimicrobial material</td><td rowspan="2">Students use EC to design a cold shipping container for a biological specimen</td><td rowspan="5">Students propose community engagement and water filtration strategies</td><td rowspan="2">NA</td></tr>
<tr><td>Spring 2017</td></tr>
<tr><td>Fall 2017</td><td rowspan="3">Students use EC to design a self-cooling water bottle</td><td rowspan="3">Students interview alumni and design a recruitment brochure</td></tr>
<tr><td>Spring 2018</td></tr>
<tr><td>Fall 2018</td></tr>
</table>

The OPE design challenge presents an entrepreneurial challenge in which students learn about oligo-phenylene ethylynenes (OPEs), an antimicrobial material, that our faculty use in their research. OPE has remarkable antimicrobial properties, has proven safe for human contact, is highly durable, and can be molded into a variety of shapes and sizes or integrated into a variety of materials. Students are tasked with designing a product that can be made from or can utilize OPE and that can be marketed and sold by a major company. It must be an application of the OPE material, such as a surface coating applied to an object already being manufactured; it may not be a wipe or spray, as these are already in development. After being scaffolded to generate ideas about what they already know about antimicrobial materials, students come up with at least ten ideas for products by considering people of all ages and of various occupations. They then choose three ideas to develop further and the instructors give them feedback on which ideas seem promising. They then choose one idea to pursue, comparing it to existing similar products in terms of the stakeholder needs and experiences, costs, and benefits. They are warned that their products will likely cost more because of the added OPE material and encouraged to consider how to minimize this difference or communicate the added benefits of their proposed product.

The acid mine drainage (AMD) design challenge was developed based on a recent regional disaster, the 2015 Gold King Mine Spill on the Animas river. This spill occurred during normal monitoring efforts, inadvertently releasing AMD into a river that flows from Colorado through New Mexico, Arizona and Utah, turning the river a vivid orange color. Using this as a case example, the challenge prompts students to identify a rural community threatened by one of the many abandoned mines in the Southwest and design a comprehensive response plan, including community engagement strategies and choosing a treatment system that could filter water for an entire community in the event of pollution from abandoned mines. Students are prompted to conduct library research on the Gold King mine spill as a case study, including the response by the EPA and the reactions of the Navajo Nation, and on abandoned mines and acid water drainage, current treatment technologies, and community engagement strategies that build trust. They then consider needs and points of view of different stakeholders:

- **Community member.** Imagine you live in a community whose water was unsafe due to acid mine drainage. Describe how you would feel and what you would need.
- **Farmer.** Imagine you are the owner of a farm and the water for your livestock appears unsafe, due to acid water drainage. Describe how you would feel and what you would need.
- **Government employee.** Imagine you work for the state government and it is your job to help in the cleanup efforts. Describe how you would feel and what you would need.

After being scaffolded to investigate and evaluate existing treatment solutions, students choose or configure an optimal design that meets needs in a balanced way while considering all requirements and constraints. For instance, a system that can filter everything out perfectly and is scaled to a small community, but that is prohibitively expensive is not an optimal solution.

Both design challenges culminate in a team pitch. Students are instructed to dress professionally, concisely explain the problem and needs addressed, share a brief story that helps the audience understand the perspective of a stakeholder and how the designed solution will change their lives for the better, explain how the solution works, and detail the cost and market potential.

Data collection & analysis

Our study received approval from our Institutional Review Board. Any reference to individuals or teams employs pseudonyms.

We video recorded all team pitches of their design solutions. We created a database of the videos and transcribed portions of the videos but conducted most analysis using the video records themselves.

We developed a coding scheme iteratively, first using an in vivo approach [38], meaning we watched the recordings and noted common themes. This included that many teams mentioned specific stakeholder points of view, described health and environmental concerns, and when their designs were costly, argued that the cost was justifiable based on saving lives. We refined these into a coding scheme based on the literature; in particular, we built on the four principles [6, 17]. We then coded the videos, refining the coding scheme to ensure our coding was reliable (Table 2).

We conducted a two-tailed sign test—a non-parametric statistical test, to contrast the design challenges in terms of the kinds of ethical considerations students raised.

Table 2. Final coding scheme used to analyze pitch videos

Code	**Description**
Person	At least one stakeholder is mentioned
Planet	Student mentions how the environment/Earth might be impacted by the design or describes environmental need
Multi-perspective	Students consider more than one perspective on the problem
Normative need	A need is described that is well within the normative experience. In AMD, this includes needs like water for drinking, cooking, bathing, watering crops and livestock, and privileged uses, like recreational uses of water. In OPE, this includes arguments that everyone needs the thing they are proposing (e.g., everyone has a cell phone, uses the toilet, etc.).
Just need	A need is described that falls outside the normative experience. In AMD, this includes cultural/spiritual uses of water/places and impacts specific to vulnerable communities/groups, such as increased mistrust or loss of income. In OPE, this includes impacts that are specific to a vulnerable/marginalized group (e.g., people with disabilities or compromised immune systems, etc.)
Feasible cost	Students propose a feasible cost. In OPE, they may explain that the cost will decrease with production or they explain how they have minimized use of OPE material in the design. In AMD, this means a cost that is not millions and generally is discussed as affordable for the community.
High cost	Students propose a high cost and admit or do not argue it will be affordable to stakeholder. In OPE, this often means the cost is 5+ times higher and no effort has been made to consider ways to make

	it affordable. In OPE, this often means the cost is millions.
Warrant cost	Students argue that the cost is justifiable because it is the right thing to do. In AMD, the cost is often assigned to the EPA or government. In OPE, the cost is often justified based on potential for lives saved.
Benefit	Student explains that the idea will benefit people or planet
Nonmaleficence	Student explains the idea is safe or won't harm people or planet.

Results & discussion

Overall, we saw few differences between the five semesters in terms of overall frequency of use of ethical reasoning. Importantly, all teams used some form of ethical reasoning in at least one pitch, and we found only one instance where a team did not use ethical reasoning in one of their pitches.

Most students not only considered at least one stakeholder point of view, but considered design problems and solutions from multiple points of view (77% in OPE, 88% in AMD challenge). In the OPE challenge, they tended to consider health care providers and patients, children and parents, or other situations in which there was a service provider and end user (e.g., a chef and diners). In the AMD challenge, they considered points of view from farmers, businesses, and families. Many design teams also offered considerations from different points of view but only referred back to the community at large. While they did not address these views tied to specific roles, they understood that communities were diverse and contained such viewpoints. For example, Jorge explained his understanding of the problem of acid mine drainage, "So growing up in New Mexico, I grew up in a part of Bernalillo County that used a lot of irrigation water, and my family maintained a small farm that had a lot of different types of produce and a lot of different types of small animals, all of which came into contact with this water that came from the Rio Grande. So, after learning about acid mine drainage, it make me realize how detrimental this could be to some families and businesses, um, not only because they put so much work and effort into their properties but sometimes that's their livelihood. For my family it wasn't but I can only imagine if it was. So it's for these people that have their whole livelihood in their land and for the people who have already been affected by acid mine drainage that I think we need to work on reversing the negative effects, um, of acid mine drainage with the least amount of negative side effects."

In general, students argued from a point of view of beneficence (93% in OPE, 63% in AMD challenge) rather than nonmaleficence (14% in OPE, 10% in AMD challenge). In the AMD challenge, they tended to consider benefits to communities in terms of health and trust and benefits to the environment and ecosystem. In the OPE challenge, they primarily considered benefits to human health with specific connections tied to the larger communities they identified with, such as nationality and citizenship. For example, a team that proposed to incorporate OPEs into a hazmat suit explained "We see a constant threat from microbials, especially deadly microbials, we see them in our past and we see them now and we can assume we are going to see them later in life. And so just in the past 2 years we have had Avian influenza, the Ebola and Zika virus, and these have killed hundreds upon thousands of people. And within these, Ebola was in Africa and there were people who were United States of America, they were citizens here and they were unable to come back home because they were afraid of contracting the virus and we didn't want it to spread out here. But if they were able to have these OPE suits where they were working with the virus they could have come home cause they wouldn't have a risk of contamination. And so, with these OPE suits we can possibly prevent such a large outbreak and hopefully give people who are working with these microbials a better chance of less contamination and just a safer environment."

Although few students made nonmaleficence arguments, these are important for engineers to consider. Any change to the environment, such as in the AMD challenge, and especially any use of a relatively new material in contact with both humans and the environment should be considered in terms of its potential to introduce new harm. However, we recognize that we did not specifically prompt students to consider this line of reasoning, though some students brought this up during in-class discussions.

Few expressed needs of marginalized or vulnerable populations (17% in OPE, 15% in AMD challenge). In the OPE challenge, these populations tended to include children, individuals with compromised immune systems, and people with limited access to clean water. For instance, one team explained their idea to coat toys with OPE for a children's hospital, "In 2015 the CDC actually ran a study where they looked at the necessity of hand washing, and what they found was that about 1.8 million children under the ages of 5 actually die from diarrheal diseases as well as pneumonia both caused by bacteria. We would like to change that, and so what we are proposing today is a product that will make, brick by brick, will build a better future for our future children and we're going to start with their toys."

In the AMD challenge, they tended to consider impacts specific to members of the Navajo Nation, people living in lower economic communities, and those who might be more affected by contaminated water, such as the elderly and very young. For instance, one team explained, "We thought it would be very inconvenient for people if they were handicapped or children, and like you know, if it were an ongoing issue like taking years to completely solve the problem you don't want to be boiling water for every meal in that time and for like elderly people." Another explained that AMD "also destroys sacred lands of Native populations such as those of the Navajo Nation. The San Juan river is especially sacred to the Navajo people and the pollution is not only linked to the destruction of their millennial owned sacred grounds but also farming land necessary to the Navajo subsistence farmers."

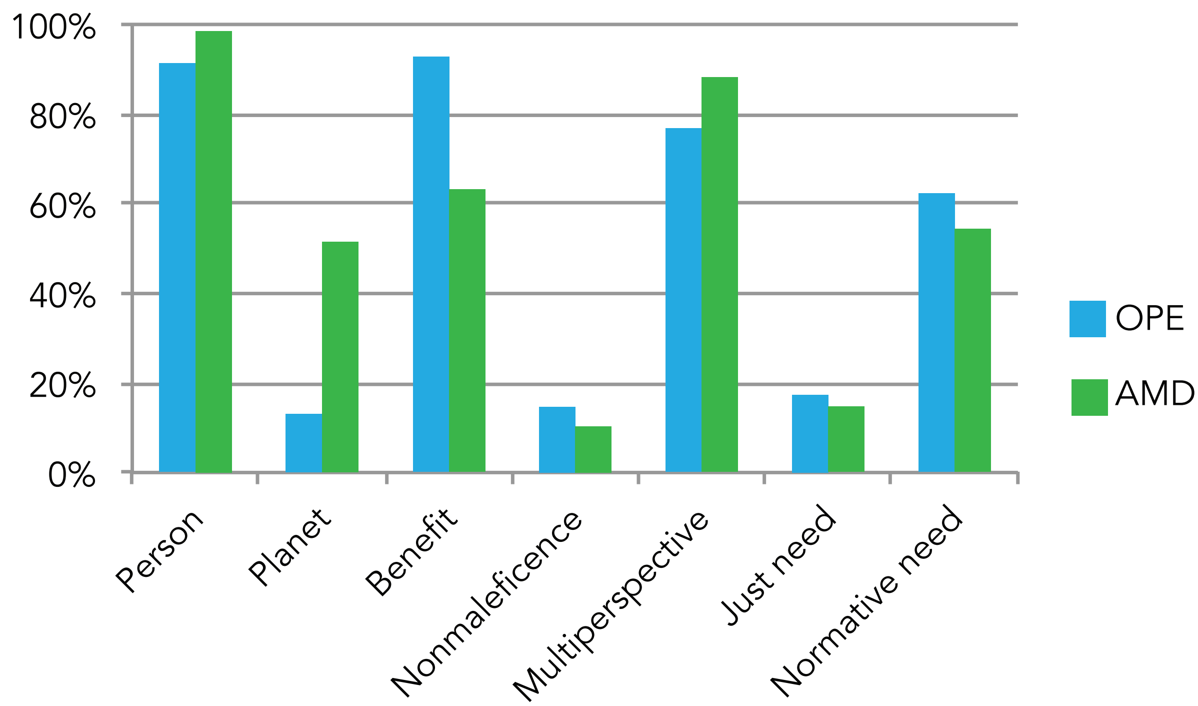

Figure 1. Percent of pitches containing each code

We compared the frequency of codes for benefit, nonmaleficence and multiple perspectives on the OPE and AMD challenges using a two-tailed sign test. There was a significant difference between the two challenges in terms of benefit, $z = 3.92$, $p < .001$. There was not a significant difference in terms of multiple perspectives, $z = 1.71$, $p > .05$, or nonmaleficence, $z = 0.90$, $p > .05$. This suggests that the challenges provided similar opportunities for students to employ ethical reasoning in many ways, but perhaps not in terms of beneficence. The entrepreneurial nature of the OPE design challenge may have more naturally prompted students to articulate benefits.

Many of the design teams took a very matter of fact approach when presenting the high cost associated with their design. In the OPE challenge, students often argued that the high cost of their proposed product was not an issue considering how the product was used. For example, one team proposed coating the latex gloves used by medial staff with the OPE solution, which could cut down on the risk of infections. Since their product was fulfilling a widespread and socially important need, they did not justify their cost: "So, we estimate about a $700 commercial price that is being said that, um, a box of 100 gloves would cost about $70,000. Which is pretty steep. Um, $635 to produce, and that's one glove." In the AMD challenge one design team related the high cost of their intervention with the longevity of the intervention with its beneficial properties: "These systems are pretty expensive, like, 500k and they also cost very much to install, but in the end they can be permanently installed. So, in the long run they can be beneficial."

Conclusions & implications

Our results demonstrate that even with limited prompting to do so, a realistic design challenge can support students to use ethical reasoning. Although we see these results as promising, we acknowledge both the limitations and future possibilities. While we analyzed data from five semesters, finding little variance from one semester to the next, we recognize that our context, as a Hispanic-serving research university, is unlike many other contexts. The diversity our students are accustomed to may have influenced their propensity to consider problems from multiple points of view and to detail benefits. We also note that by restricting our dataset to only the final pitches, which were limited in time and by students' comfort with public speaking, we may have missed other forms of ethical reasoning that they engaged in, resulting in an underrepresentation of their actual understanding. Still, we see this as an important lens into their thinking, as they made choices about what information to foreground.

It is important to note that we did not specifically consider supporting ethical reasoning when developing the design challenges. That all teams engaged in some form of ethical reasoning suggests to us that design challenges like these provide a natural context for first-year students to begin building their ethical reasoning skills. However, we also note that there is great variability in design challenges offered to first-year students. It is not uncommon to provide decontextualized experiences with no sense of client or stakeholder. This is, in part, because managing authentic clients and stakeholders is challenging and time-consuming work. We deliberately developed challenges that we thought would be relevant to students' lives and build upon their everyday and cultural experiences [34-37]. We conjecture that this aspect is central to students being readily able to use ethical reasoning without specific prompting to do so.

Based on our results, we see potential benefit from scaffolding students to consider nonmaleficence. Students easily articulated benefits of their designs, but few explained the potential for harm. Adding a specific prompt to consider steps that would need to be taken to resolve the potential for harm might aid students to consider this aspect and deepen their ethical reasoning. Likewise, additional scaffolding could be added to support students to consider the just distribution of risks and benefits. In future, we plan to add the following scaffolding to both challenges:

> *[nonmaleficence]* In addition to considering the benefits of a design, engineers must also consider unintended risks and harm, including side effects of medicines, negative impacts on communities and environments, and so forth. Are there any potential risks to the stakeholders or the environment that could come about as a result of your design solution? Describe some of the steps you think might need to be taken to determine if your design might cause unintended harm.
>
> *[just distribution of risks and benefits]* List all of the stakeholders you can think of who might be affected by your design. Consider diversity within general categories of stakeholder. For instance, if you list "community member" also consider more specific stakeholders like "elderly community member" "community member who is blind" or "community member who is a member of Navajo Nation."

Are any of these stakeholders likely to benefit more that others from your design or have greater need for it? Will they be able to afford it and access it? If not, what are some ways you can make it more affordable or accessible to those who need it most?

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