

Commonality of Failure Modes in New Engineering Program Development

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Introduction

New engineering programs are added each year across the US and abroad, but anyone who has started a new program knows that there are numerous “start-up” challenges to designing and launching a new program. The University of North Carolina (UNC) Chapel Hill, which is starting a new undergraduate multi-disciplinary engineering major, and Franklin W. Olin College of Engineering (Olin), which has “drive change in engineering education” as part of its mission, partnered to create EMERGE (Entrepreneurially Minded Engineering Resource Group for Educators) in the summer of 2020. EMERGE began as a free, optional add-on workshop to the annual Olin Summer Institute and has since grown into a strong cohort of over 40 institutions that meet monthly over Zoom and in person once a year. The program is facilitated by Olin and UNC faculty and staff and has a basis of entrepreneurial-minded learning in its facilitation [1]. The second annual in-person retreat will take place in summer 2023 with activities designed to help guide new institutions through the development stages of their programming. The schools participating in the EMERGE program range from those in the early planning stages for an engineering program to those that have launched programs recently to those that have more established programs, including several who have received ABET accreditation. Recognizing that starting, and then maintaining, a healthy, entrepreneurially minded engineering program is a multi-year process with numerous challenges, the EMERGE program aims to be a resource to all by supporting program and faculty development of new programs.

There is a tendency in new program development to focus on a discussion of 'what works'. Contrarily, in accordance with Kanban philosophy, there is no failure if something is learned from the experience [2]. In a world of 'fail forward', 'fail fast' or 'move fast and break stuff', innovation from a trial-and-error approach involves implementing/operationalizing changes gleaned from these trials. However, these trials and failures are often not published, which results in a collective slowing of progress. "Failure modes" means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual [3]. In this case study the failure modes are ways in which program creation is inhibited or retarded. The EMERGE cohort through this study aims to enable efficient programming development by sharing our failures in addition to trumpeting our successes.

The goal of the study presented here was to identify the failure modes most often encountered by emerging programs and discuss ways in which developing programs have solved these challenges, as well as discuss strategies for dealing with unresolved issues. It is hoped that by having open and transparent publication of the challenges faced and solutions found that more effective program development in emergent engineering programs can be realized.

Methodology

Development of the methodology employed for investigation of failure modes in new programming was initiated during the EMERGE retreat. The retreat organizers allowed for space

in the programming to organically grow initiatives, and in relation to the goals-activities-products-assessment (GAPA) framework activity [4], it was observed that we often correlate successes but rarely discuss failures. The envisioned program was broken down by the authors into four stages of development: creation of an initial pool of discussed failure modes, a survey to curate additional failure modes from the EMERGE cohort, a survey to rank collected failure modes amongst the participants, and a workshop to discuss ways in which observed failure modes persist, have been successfully solved, and propose solutions to unresolved issues from participants in the network.

The creation of the initial pool of failure modes occurred over approximately a one hour round table discussion amongst the lead authors. The members of the round table discussion were attendees of the EMERGE in person meeting and chose to participate in discussing this topic from 5 topics offered. The members of the initial table, the authors, were from DePaul University, Earlham College, University of Ottawa, University of San Francisco, and Stevenson University. Characteristics of the authors' institutions are provided in Table 1. Reflecting on personal experiences in program development and sharing stories, the activity generated about 40 of the initial failure mode statements. The conversational interplay aided in uncovering additional features of interest as questions to the group were further developed into additional branches of detail.

The first survey sent out gave an example of a failure mode and asked members to submit examples of their own. The survey was organized into three prompts - Challenges: Uncertainty from unknown structures, Stall points: Inaction from a limiting process, and Battles: Experiences of conflict. The survey was active for one month and generated an additional 10-12 statements from five submitters. The submitted statements were pooled and the authors discussed through a shared document the clarification or amalgamation of statements to form a collected pool of 48 statements.

The second online survey consisting of those 48 statements, grouped by theme, along a Likert scale from 1 to 5 with a 1 indicating the issue does not apply to the program development and a 5 indicating the issue strongly applies to the program development was sent to 77 participants. The Likert scale had five options, but only 3 were labelled in order to allow users to choose between two options without it being rigidly defined if they were uncertain about the confidence of the reply. This survey was available for 1.5 months and was completed by faculty members of 15 US institutions and 2 international (Canada and Vietnam) institutions. Table 1 provides further details regarding the institutional characteristics of the survey respondents. As an illustration of the demographic, the tuition at the US-based institutions in mean (standard deviation) was \$33,752 (\$17,003) with an enrollment of 18,951 (27,091). Statements that received a rating of 4 or 5 from more than 29% of respondents were grouped thematically by the authors and work groups were used to determine solutions/strategies to overcome these obstacles. This represented 5/17 of the respondents indicating this selection as of importance. The cut-off of 5/17 respondents rating an item with a 4 or 5 was somewhat chosen arbitrarily. There were 4 items (8% of the items) where more than 6/17 of respondents gave a rating of 4 or 5. There were 19 items (35% of the items) where more than 5/17 of respondents gave a rating of 4 or 5, and there

were 30 items (62% of the items) that received a rating of 4 or 5 from more than 4/17 of respondents.

As part of a regularly scheduled EMERGE meeting, participants selected one of 4 breakout rooms where one of the four identified themes were chosen as the topic of discussion. The breakout rooms were attended by faculty from 16 US-based institutions and 2 international institutions (Canada and Vietnam). The US-based institutions cost \$38,436 (\$17,952) with enrollment of 9,460 (13,665), see Table 1 for further details.

Table 1: Characteristics of the home institution of survey respondents. The tuition, enrollment, region, and size of the US-based institutions are further detailed in the table below. The US-based institutions were broken down by the Carnegie classification system [5] where large institutions enroll 10,000 students or more, medium institutions enroll 3,000 to 9,999 students, small institutions enroll 1,000 to 2,999 students and very small institutions enroll fewer than 1,000 students.

		Round table	1st survey	2nd survey	Break-out session
School location	US	4	Fully Anonymous	15	16
	International	1		2	2
School type	public	1		5	5
	private	4		12	13
Tuition		\$46,792 (\$7,473)		\$33,752 (\$17,003)	\$38,436 (\$17,952)
Enrollment		7,128 (6,171)		18,951 (27,091)	9,460 (13,665)
Region	mid-Atlantic	1		3	1
	Northeast	0		0	1
	Midwest	2		1	1
	South	0		6	5
	West	1	5	4	
School size	very small (<1000)	1	0	3	
	small (1000-2999)	0	1	1	
	medium (3000-9999)	1	8	8	
	large (>9999)	1	6	4	

Results and Discussion

The results and discussion are broken down into the survey result categories with commentary from the workshop activity captured in-line with the text to connect the results. A further breakdown of discussion from the workshop follows, where the EMERGE cohort discussed the implications of this study and the findings in general.

Nineteen of the 48 statements (items 4, 5, 6, 8, 10, 13, 15, 17, 19, 23, 24, 28, 40, 41, 43, 45, 46, 47, and 48) were identified as applying to program development (rating of 4) or strongly applying to program development (rating of 5) with more than 29% of respondents rating these statements as a 4 or 5. The statements were grouped into 4 categories: University and community involvement and engagement (figure 1), Student and faculty health and well-being (figure 2), Inter-departmental, university, and accreditation issues (figure 3), and Planning for the future, allocation of resources (figure 4). Figures 1-4 show the relative frequency for the ratings of each item.

University and community involvement and engagement

Items 5, 10, and 19 received a rating of 4 or 5 at a frequency of 29%. These items were thematically grouped under the heading “University and community involvement and engagement (Figure 1).

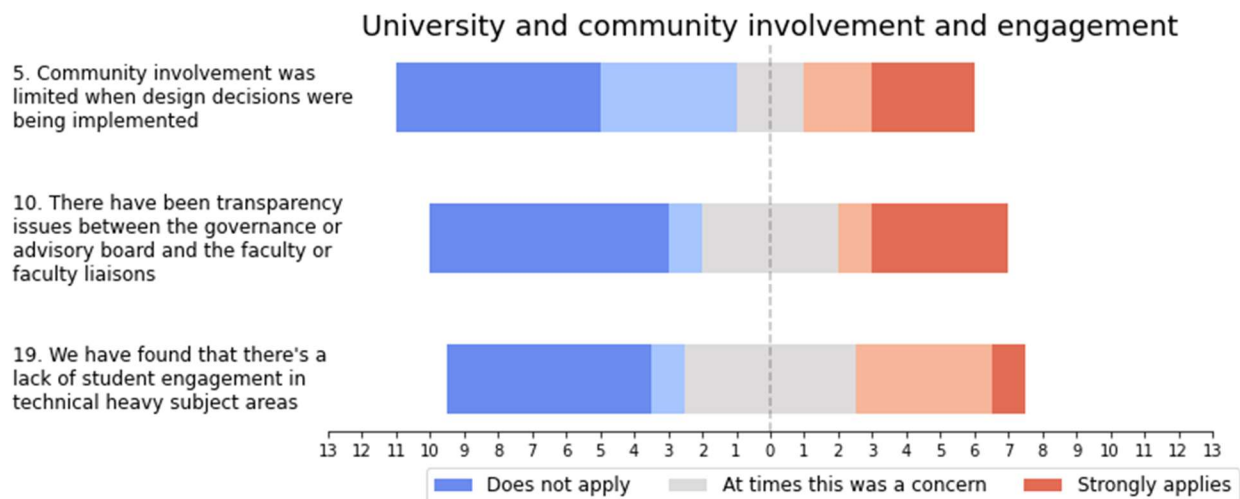


Figure 1 - University and community involvement and engagement

During the breakout discussion regarding university and community involvement and engagement, a key issue was identified which may be contributing to these issues. The workgroup proposed that all relevant stakeholders may not have been involved in all the stages of program development. Failure to include these stakeholders resulted in ignorance of the perspective and viewpoints of key stakeholders. Examples provided by the work group included whether governing boards understood the perspective of the faculty and deans of the unit. It was proposed that issues like this may arise from engineering programs being developed at institutions where engineering programs exist compared to traditionally liberal arts colleges where engineering programs may be more novel.

The proposed solution highlighted the need to broadly include representation from all members of the campus, community, and external partners when the initial design needs are established.

Student and faculty health and well-being

Items 13, 15, 17, 24, 28, 40 were scored 4 or 5 with a frequency of 29%. These items were grouped thematically under the heading “Student and faculty health and well-being” (Figure 2).

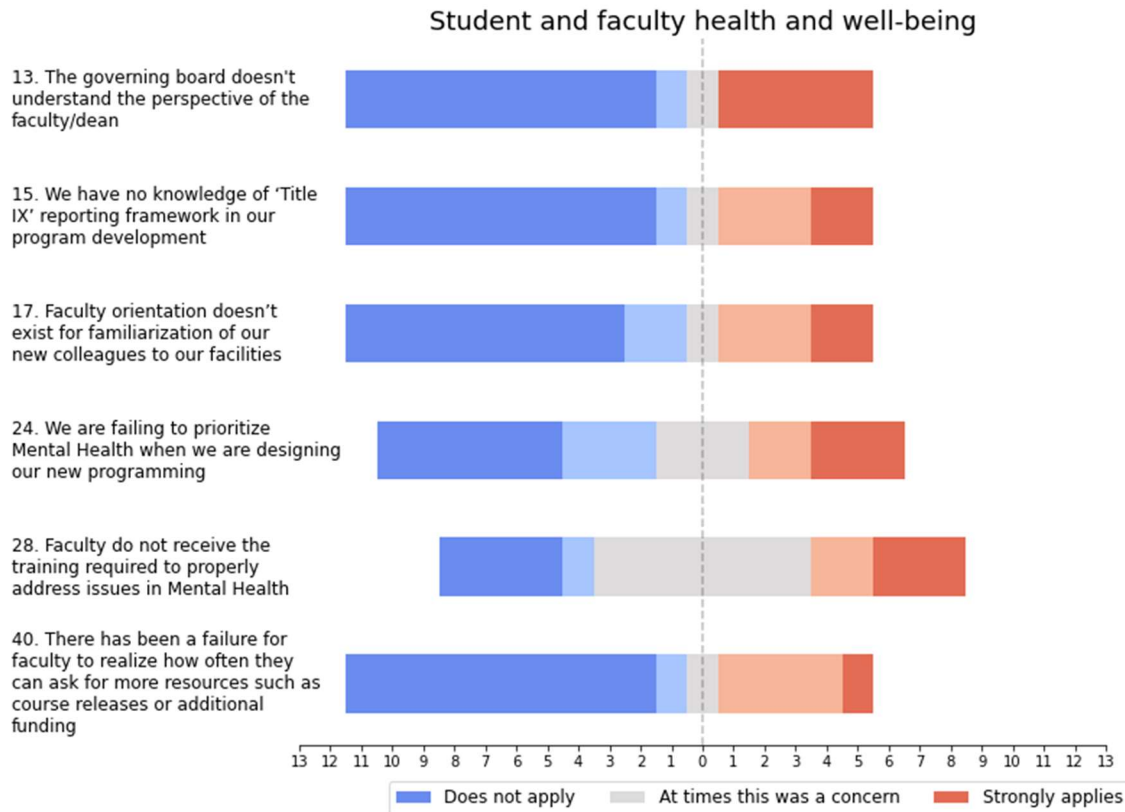


Figure 2 - Student and faculty health and well-being

Despite health and wellbeing being one of the primary foundations on Maslow's Hierarchy of Needs [6] we often forget about these basics while we develop plans in higher education.

Concerning Item 13 (The governing board does not understand the perspective of the Faculty/Dean) - with disconnected decision makers a problem can arise in which information only seems to flow in one direction. For this particular concern there was not a sense that faculty (trained educators with a background in philosophy of education) could steer the direction of best practice as the opinion and perspectives of others were more highly valued. Motivation for how prioritization is meted is personal, regardless of position on the decision food chain, but not having professional training respected when the decisions were often counterpoint shows challenges in the survivability of our institutions. Catering to external political and economic drivers can become a hallmark of capitalistic systems for fear of survivability, and care must be taken to have our institutions respond to industry with leadership to explore alternative cultural values. The opportunity to 'redesign' a new program is often never allowed, so having the courage to be bold, innovative and visionary requires a disconnect from these political-economic forces.

Title IX attests to the equality between the sexes regarding access to education. Despite this fact and the fact that the respondents did not find that this is a challenge for our programming, there is a severe lack of equal representation of sexes in Engineering. Care is needed in our programming to re-evaluate this feature as we consider what skills we prioritize and if there is a gendered bias to their 'need'. There may be an opportunity to follow in the footsteps of Smith College to look for best practices in disgendering engineering education, however without the segregation that allowed this progress to thrive. In any regard, expert advice in the equity, diversity, and inclusion (EDI) transformation of our programming is improving, and access to these services to continue to attend to this important barrier in cultural perspectives of inequality. While Title IX as written attends to gendered discrimination it is important to carry forward this equality afforded to gender towards all ways our programming may be invisibly discriminatory.

Constraints such as learning new systems have not found to be a substantial need, although noted for some programs (Item 17), however this training may not be evenly distributed. One such example of distribution of training can be addressed with Item 28 - Faculty do not receive the training required to properly address issues in Mental Health. Common discussions regarding "As we want engineers to be gritty, how do we balance mental health and resilience?" took place without resolution. This may be a common challenge, but it does not get addressed as prominently in new and developing programs. Given item 24 - We are failing to prioritize Mental Health when we are designing our new programming, there is certainly an effort to prioritize this in our programming, but training for faculty should be considered to abate this part of the puzzle. There is also the case of personal mental health to attend to - the tenure push is toxic to work-life balance; unless there is a 'scorecard' that reflects this virtue, why would an educator prioritize this? There may be additional requirements when starting new programming, to innovate and find a way where we can attend to this challenge in our promotions and retention policy.

Communication from the group for Item 40 - There has been a failure for faculty to realize how often they can ask for more resources such as course releases or additional funding, was that there was not found to be a barrier if one is to simply ask - This is tied to the planning and shortfall of funds, with adequate knowledge and open communication this can be abated. At some institutions the financial health of the programming is shared, and this can be an opening for allowing for additional questions to be fielded such as when the challenges arise of 'is there funding for this innovation?'

Inter-departmental, university, and accreditation issues

Items 4, 8, and 23 were rated 4 or 5 with a frequency of 29%, 29%, and 53%, respectively, and these items were grouped under the theme "Inter-departmental, university, and accreditation issues" (Figure 3).

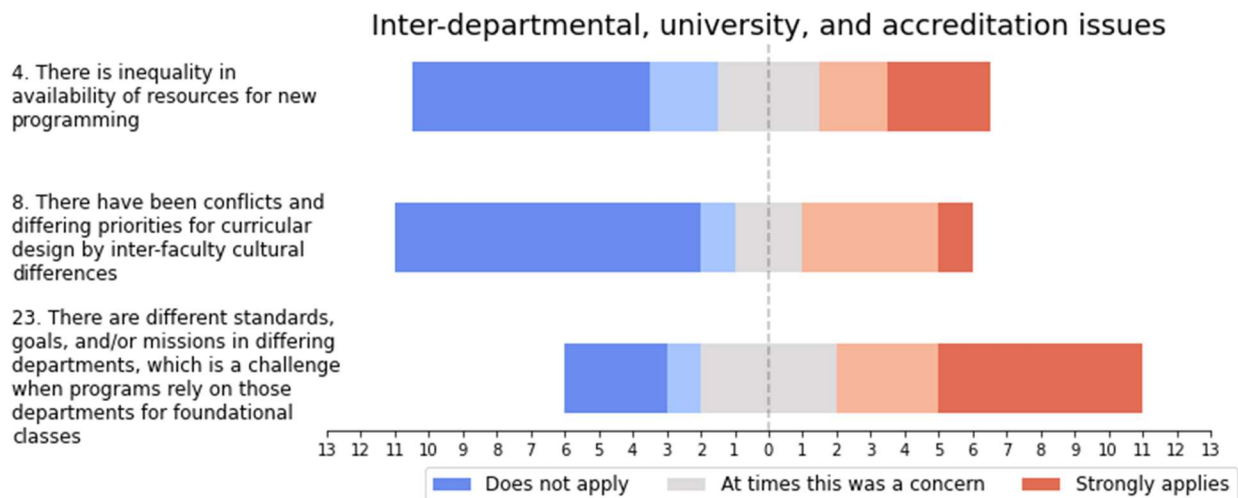


Figure 3 - Inter-departmental, university, and accreditation issues

In the breakout session focused on inter-departmental, university, and accreditation issues, several strategies were identified to help new programs navigate the administrative and budgetary structures at the college and university levels. Issues related to inequity in the availability of resources for new programs may be present to different extents at larger versus smaller institutions, and also among institutions that bring in R1 research-based revenue sources and those that are primarily tuition-dependent. The influence of institution size and revenue could be explored in more detail in a future study.

The majority of the programs surveyed indicated that having to work on common curriculum elements, such as common foundational courses in the first and second year of new programs, with multiple departments or colleges created issues with program development. Beyond focusing on buy-in from other science, technology, engineering, and mathematics (STEM) departments in the process, strategies for forming closer connections with other units in order to develop shared goals and common instructional and assessment methods were discussed. These included large-scale decisions, such as choosing to merge an engineering college with the college of science at the institution to better support the collaborative curriculum initiatives that were needed.

Planning for the future, allocation of resources

Items 6, 41, 43, 45, 46, 47, and 48 were rated with a score of 4 or 5 with a frequency of 35%, 29%, 29%, 47%, 29%, 29%, and 35%, respectively (shown in Figure 4). These items were grouped under the theme “planning for the future, allocation of resources”.

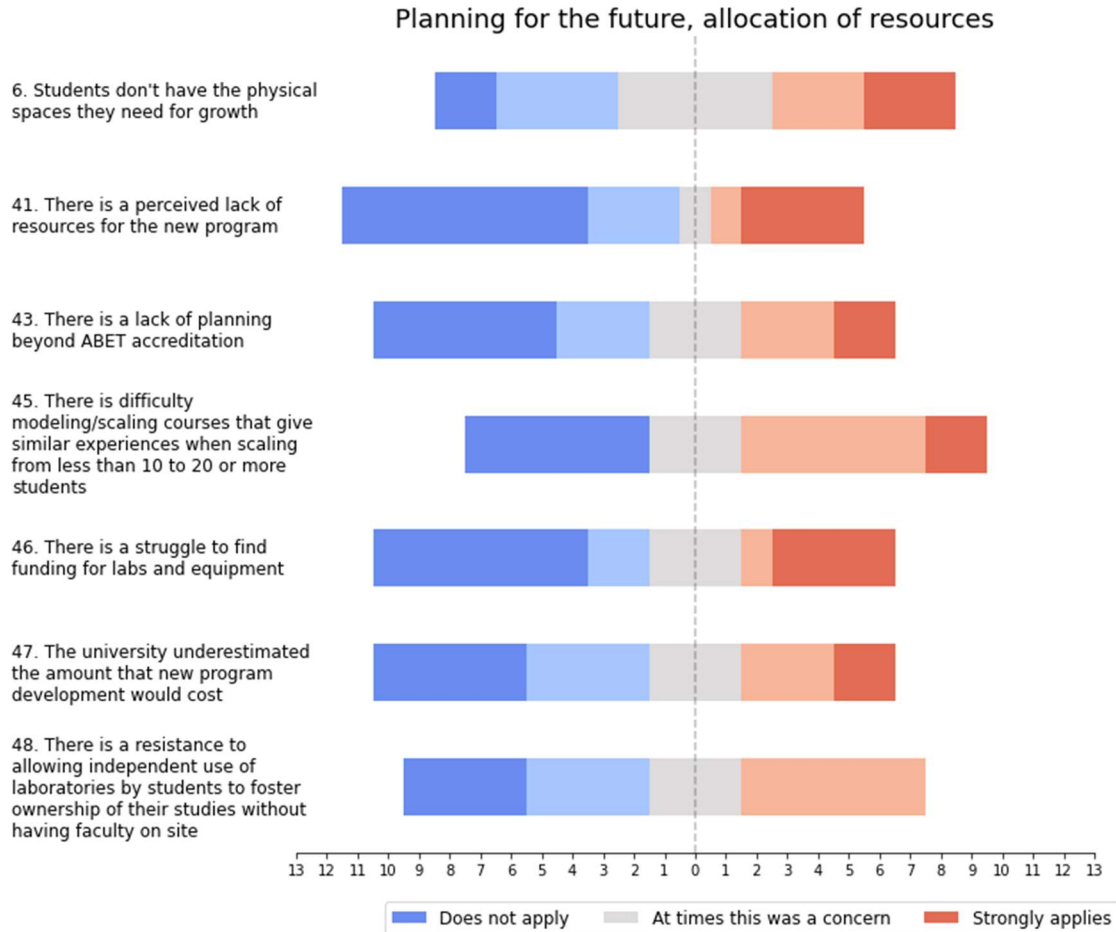


Figure 4 - Planning for the future, allocation of resources

The strategies that were identified during the breakout discussion by the workshop participants focused on the planning for the future, allocation of resources issues included recommendations to pursue grant funding and to consider seeking out partnerships with companies and governmental labs. Specific advice included having the engineering program work closely with the institution on budget planning and on providing resources to help transition between funding received, or expected, from external grants. To help resolve issues related to spaces for student work, projects, and labs, the recommendations were focused on clearly identifying safety issues related to the activities allowed in the spaces, the time of the day the spaces are open to students, and the need to have secured access and monitoring of the spaces. Other recommendations made by the workshop participants included taking advantage of surplus or rotated equipment programs that federal labs and some industry partners may run to help reduce the funds that the programs themselves must provide.

Five of the seven statements in this theme fall into a potentially more informative pattern. In addition to being rated a 4 or 5 with a frequency of 29% or greater, statements 41, 43, 45, 46, and 47 were also all rated with a score of 1 (does not apply to our program development) with a frequency of 29% or greater. The binormal nature, or inverted bell-structure, of the responses

may suggest that while a subset of programs experience these struggles there are also many possible solutions to the problem, which have already been implemented by those programs that rated the statement a 1. Therefore, the areas covered by these five statements represent topics of conversation that have the potential to be extremely fruitful to programs early in the development process. The supposition about the nature of the bimodal responses was anecdotally confirmed by participants in the workshop where many of them shared actions their programs have taken to overcome the problems.

Strategies related to statements 41, 46, and 47, which are all financial in nature, centered on governmental grants for new and emerging programs and company partnerships. Importantly, for those on governmental grants, specific advice was given to ensure the health of the program beyond the end date of the grant by working closely with the institution on budget and resource planning well in advance of the transition off the external grant. Other recommendations made by the workshop participants included taking advantage of surplus or rotated equipment programs that federal labs and some industry partners may run to help reduce the funds that the programs themselves must provide. Due to the large differences in how public and private institutions are funded, it should also be noted that the pattern of responses to these statements by public and private institutions may differ significantly.

When forming a new program, much of the effort is concentrated on launching the program and reaching the accreditation milestone. Therefore, the trajectory of the program post-accreditation can be easily overlooked as statements 6, 43, and 45 suggest. The binormal nature of the responses to statements 43 and 45 suggest there may be common strategies to explore to overcome these challenges, similar to the financial challenges discussed previously. Statement 6, which is related to physical spaces needed for growth, is a combination of finances as well as location of the institution. Intercity campuses face very different challenges when it comes to expansion compared to rural campuses, and the low frequency of 1's in the responses suggest there might not be straightforward strategies to overcoming this obstacle.

Of the 19 statements that were rated with a score of 4 or 5 with a frequency of 29% or greater, statement 48, which deals with independent access to laboratories by students, is the only one where no one responded with a 5. These results suggest that while independent access for students is a concern, it is not one of the most pressing concerns for new programs. This may be tied to availability of resources related to running an academic makerspace, including different models for handling safety, finances, and staffing [7,8]. Additionally, these insights and models are often applicable to other types of laboratories. Importantly, the option of supervised hours only provides a usable solution for new programs as they determine the methods for fostering student ownership that best fit their institution. The availability of such an option may relieve the urgency on this issue. During the workshop, those programs that currently have a culture of independent access, safety was highlighted as the most important factor to consider. Students are required to be on a buddy system outside of supervised hours and are also required to re-take the safety training at the beginning of each academic year. Independent access also comes with a small financial cost as the accidental loss of small equipment is unavoidable.

Most important items for new program development

Considering only items that received a score of 4 or 5 with a relative frequency greater than 0.3, leaves items 6, 48, 45, and 23 with relative frequencies of 35%, 35%, 47%, and 53%. The items identified as relating to program development issues, which are listed in order of increasing relative frequency, were the following:

- 6. Students don't have the physical spaces they need for growth
- 48. There is a resistance to allowing independent use of laboratories by students to foster ownership of their studies without having faculty on site
- 45. There is difficulty modeling/scaling courses that give similar experiences when scaling from less than 10 to 20 or more students
- 23. There are different standards, goals, and/or missions in differing departments, which is a challenge when programs rely on those departments for foundational classes

These items fall under the theme of planning for the future, allocation of resources and inter-departmental, university, and accreditation issues. The items receiving the highest frequency of 4 or 5 responses identified issues involved in scaling of program elements and in dealing with the needs of different departments. The other two items identified potential difficulties related to dedicating space for student-centered activities.

Success in dealing with differing departments was reported by the workshop participants in the form of getting buy-in from deans of other departments well prior to new program application. In one instance, the program director independently worked with deans across the campus to ensure all challenges to program development were pre-solved before submission for formal new-program application. This of course did not solve all the problems in this regard, as when given an opportunity to object, individual professors broke ranks with their department chairs to air grievances against the purported deficiencies of the program in a public forum despite being invited privately to address these issues before any formal process had begun. What this shows is that even within departments there are personal opinions that run counter-current to institutional co-operation, and perhaps a closer look on inter-departmental tribalism is also worth challenging to ensure that the mission and vision of the university as a whole is in unity.

Additional insight from workshop participation

The workshop highlighted the need to include broad representation from stakeholders, particularly when determining the initial needs of the program. This may be an issue to a greater degree at institutions where the engineering program is being developed if the program will be the first engineering program developed at that institution. In other words, has another unit been developed with similar needs. Alternatively, for example, a new engineering department may rely on other, non-engineering, departments for portions of their curriculum and differences in their respective policies and management may result in obstacles or redundant policy/procedure. Failure to include relevant stakeholders may result in organizational or structural mechanisms or policy that impede or delay new program development while 'workarounds or changes in regulations are developed. However, these sentiments may not recognize the greater burden of top-down policy which may reduce agility, autonomy, and innovation [9,10]. Enhancing agency

and autonomy of new program development may represent an ideal for fostering agility, autonomy, and innovation.

Conclusion

While the binormal distribution or inverted bell-structure of many of the failure modes analyzed highlighted many common features present in new engineering program development, further analysis is warranted to uncover additional correlations within this rich dataset. Although the data showed little homogeneity, one clear trend that has been ever-present in the EMERGE discussions is the need for institutions to forge and hold their identity as a key to successful development. These disparate results may point towards how each identity has key features that may make it difficult to predict what challenges will be faced in the future, but hopefully this breakdown allows for insights into what common modes exist and ways by which to amend them.

Future work will consider the effect of enrollment, tuition cost, region, private vs. public etc. on the rating for the items as in discussions there was additional insight regarding how the institution type is likely correlated to the specific problems they faced. This future work will also include additional questions to determine whether faculty position, i.e. assistant professor, professor, unit head, or timeline with respect to accreditation has an impact on item rating. Finally, targeted interviews will be conducted to better understand how different institutions dealt with or are dealing with the most important items for new program development.

Acknowledgements

The Authors would graciously like to thank the KEEN network and EMERGE organizers for travel funding and for providing a fertile and fruitful environment for liberal discussion of the issues presented in the article. In particular, the Authors would like to thank Richard Goldberg at UNC and Jessica Townsend, Rob Martello and Scott Hersey at Olin College for their informative workshops and meeting activities, and endless supportive discussions throughout and beyond meeting times.

All of the authors of the article participated equally in the workshop to create the ideation behind this inquiry and DRB participated in the workshop as a facilitator alongside the Olin College and UNC EMERGE organizers. DRB was responsible for organization of the surveys and workshop for collecting the results, as well as final editing of the article. JB was responsible for data analysis, ML provided graphics for the article, GS, JB and AR supported DRB in editing of the surveys and GS, AR, JB and DRB provided discussion of results and conclusions.

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