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Entrepreneurial thinking in interdisciplinary student teams

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ABSTRACT

Our work investigates students' perception of collaborative expertise and the role of inquiry-based learning in the context of team-based entrepreneurship education. Specifically, we examine students' perception of communication, division of work, shared goals, team conflicts and leadership in their respective teams. In addition, we look at the role that experts play in constructing students' understanding and learning when engaging in entrepreneurial ventures. To that purpose we extracted the types of sources that teams used to validate their hypotheses about revenue streams, customer relationships, or value propositions. We are using a mixed-method approach to data collection through peer-reviews, business model canvases, and status reports. This paper reports results from a study implemented in a graduate-level entrepreneurship course with a focus on sustainability and energy. Results of the peer-reviews indicate that composite scores increased between the midpoint and the end of the course. Although, female students received higher evaluations than male students, these differences were not statistically significant. The status reports and business model canvases revealed that teams utilize a range of first-hand and public sources such as expert interviews, publications and self-generated calculations to construct their business models. Finally, we found that teams engaged with experts from a variety of fields and job functions, ranging from fellow students to managers.

Key Words: Entrepreneurship, Collaboration, Sustainability and Energy

INTRODUCTION

Entrepreneurship education plays a critical role in providing engineering students with the necessary skills and content knowledge to collaboratively develop products and services in a rapidly changing technological and market environment [1]. The process of entrepreneurial thinking and venture formation, requires a complex set of skills such as opportunity recognition and development [2–4], entrepreneurial alertness [5,6], business model development [7,8], social capital [9–11], managing ambiguity and uncertainty [12,13], and raising venture capital [14,15]. For many years, however, researchers in entrepreneurship education have focused on individual learning and development of entrepreneurial skills and knowledge.

Therefore, many colleges and universities have started to incorporate interdisciplinary team experiences in their entrepreneurship courses and programs [16–18]. Interdisciplinary teams in educational settings are often assembled based on students' educational backgrounds (e.g. technical, business or law) and skills (e.g. programming, business model development, or understanding the legal implications in the creation of intellectual property). The interest in teams also reflects prevalent insights from other areas of business, science, and engineering in which collaborative structures dominate the creation of new ideas, concepts, methods and tools [19–21].

Adding teams to the entrepreneurial process, however, requires careful consideration as team performance can depend on many factors including cognitive ability [22–25], diversity [26–30], team size [31–37], psychological safety [38–41], level of interdependence and autonomy [42–44], task type [45,46], shared mental models [47–51], or the presence of team conflict [52–56]. For example, Smith et al. [57] engaged design students and professionals in simulated design tasks to compare their internal processes in terms of project and time management, information exchange, problem identification and evaluation, and synthesis. Using interaction analysis they found that student teams were more likely to disregard detailed design specifications and less likely to utilize early iterations to obtain more information about the design space. Bacon et al. [58] argued that the quality of students' team experiences affects their learning. They suggest that students should self-select their teams, avoid changing teams frequently, and that they should be given adequate descriptions of outcomes and processes. Hirsch et al. [59] used reflective activities such as team memos to better understand the factors that students associate with successful teamwork. They found that students recognized many crucial aspects of collaborative design such as problem identification and analysis, communication, and open-mindedness, supporting previous work on the use of reflection to build collaborative expertise [59–61].

In addition, research on document variance and textual coherence revealed that lower performing teams showed a positive correlation between their ability to compose a coherent description of their design concepts and their overall design performance [62]. Results from a research study conducted by Laeser et al. [63] suggest that the gender composition of teams influenced the interactions between team members, but also had an impact on the quality of their final reports. With regards to the role adoption in student teams, Meadows et el. [64] found through the analysis of students' oral presentations that female students are less likely to present the technical details of the project, and more likely to speak shorter and answer fewer audience questions than male students. Woolley et al. [25] found that the proportion of females positively correlated with collective intelligence, mediated by social sensitivity, with female participants scoring higher on that variable than male participants.

Another important issue in effectively training novice entrepreneurs is to equip them with tools to avoid typical pitfalls of starting a new venture such as counterfactual thinking, self-serving bias, planning fallacy, overconfidence or representativeness errors, and misguided belief in the law of small numbers [65–68]. For example, Kahneman and Lovallo [65] argued that entrepreneurs tend to be overly optimistic, leading to "cognitive blind spots". Consistent with this argument, Simon et al. [68] found that individuals who believed in the law of small numbers and had a tendency to overestimate their control of events tend to underestimate the riskiness of a new venture. Therefore, the theory of cognitive apprenticeship [69-71] and research in inquiry-based learning [72,73] offer a promising path to help entrepreneurs in the making to reduce cognitive biases by engaging in a rigorous process of inquiry that includes epistemic discourse, hypothesis generation and validation, use of outside feedback, and synthesis of an effective business model. For example, in a study of students' conceptual understanding of electricity Kelly et al. [74] used Toulmin maps [75] to assess the conceptual adequacy of their data, warrants and claims.

We consider three questions to come at this aspect of entrepreneurial practice. First, do students' collaborative contributions improve over time? Second, what types of sources are teams using to validate their hypotheses? Third, how do students use expert advice to develop their business models?

Our study builds on research examining the structure of students' arguments using Toulmin's argument structure of claims, data, and warrants to make judgments about the conceptual adequacy of their claims [74,76,77]. To that purpose we will analyze peer-reviews, status reports and business model canvases (BMCs), to extract hypotheses and their validations. Particularly, BMCs provided us with relevant aspects of the future venture such as the value proposition, key partners and resources and cost structure, retracing students' steps and constructing an overall picture of their process of forming a new venture.

DATA COLLECTION AND ANALYSIS

Data was collected during the winter quarter 2012 in an interdisciplinary innovation and entrepreneurship course focused on energy and sustainability, totaling 7 teams (46 students total). Each team consisted of 5-9 students enrolled in business, engineering, law, and arts and sciences. The course curricula provided an experience in interdisciplinary collaboration, opportunity recognition, needs finding, ideation, business model and product/service development, market analysis, and acquisition of start-up funding. The course was open to graduate and selected undergraduate students. Project partners included Argonne National Lab, and various other departments at Northwestern University. Every team worked with their project partner as well as a group of stakeholders (e.g. advisors, experts, or practicing entrepreneurs) with relevant experience and expertise. Furthermore, each team was assigned one faculty director that was responsible for grading as well as helping the teams find experts or other resources. Five faculty directors shared the responsibility for all seven teams. For context, examples of the entrepreneurial projects: 1) Easy-to-install solar panels (SoPan), 2) Waste Plastic Nanomaterials (NanoPlast), 3) Transportation Emission Reduction (EmRed), 4) Radioactive Materials Tracking (RadMatTrac), 5) Titanium Dioxide Water Purification (WaterPur), 6) Energy efficiency platform (EnEff), and 7) Silicon Graphene Nanocomposite Anode (SiNano).

This paper draws from three different data sets, namely peer-reviews, business model canvases, and status reports including supporting documentation. Figure 1 shows class deliverables and a short description of students' tasks. For our analysis we mainly focused on students' business model canvases (BMC) and weekly status reports. BMCs and weekly status reports were submitted through the online tools called *Thinkfuse* and *Lean Launch Lab* [78]. In *Thinkfuse*, teams were encouraged to include their insights into business model development, a list of completed and pending tasks, who they talked to about their business ideas, and any other aspects with which the team needed help in developing their business venture. All members of the team were expected to contribute to the variety of class deliverables. Once the report was submitted to *Thinkfuse*, all stakeholders (e.g. advisors, experts, etc.) were notified and could then reply and provide some feedback. Note: Thinkfuse was developed by the startup company Thinkfuse Inc. However, as of 07/25/2012 ThinkfuseInc: was bought by Salesforce and the *Thinkfuse* system was deactivated.

In *Lean Launch Lab*, teams were asked to generate and validate hypotheses about the nine dimensions of the BMC namely key partners, key activities, key resources, the value proposition, cost structure, revenue streams, customer relationships and channels. As with *Thinkfuse,* advisors and instructors were notified of any changes and could respond with feedback. Any supporting documentation such as market research, technical publications or web links could be included in both *Thinkfuse* and *Lean Launch Lab*. Table 1 shows some of the questions used to guide students' responses in each BMC category.

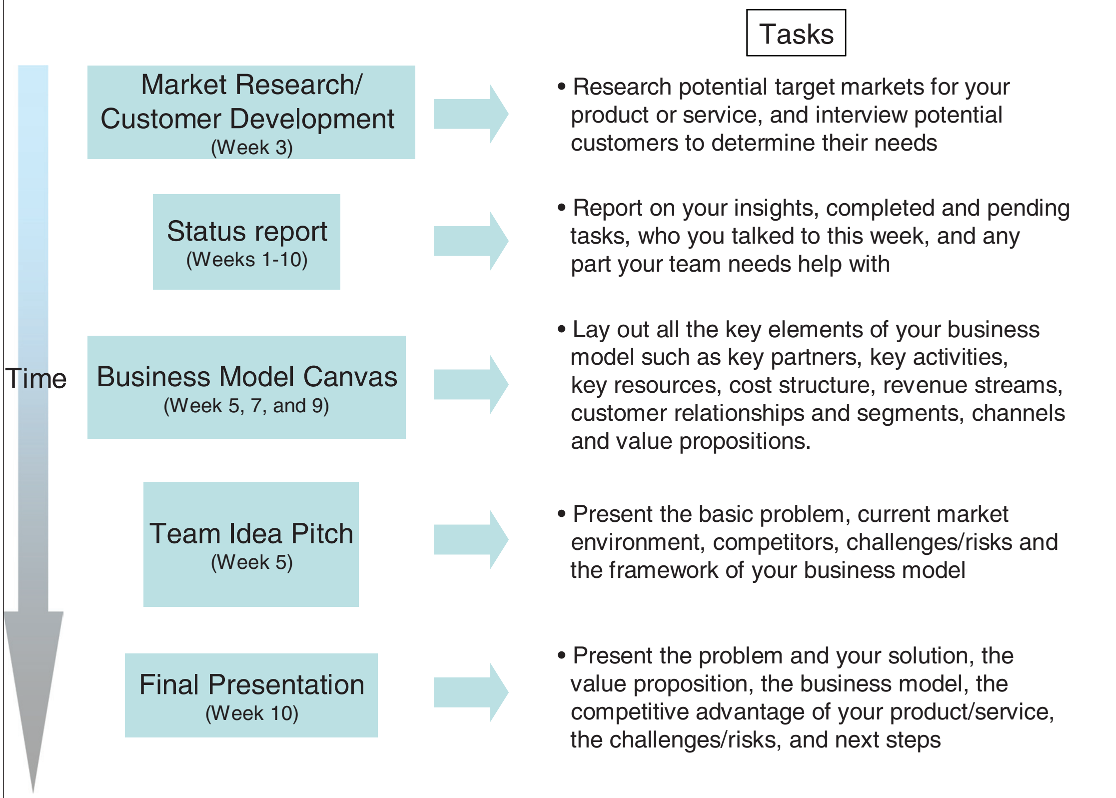

Figure 1. Team deliverables for a team-based entrepreneurship course.

BMC category	Questions
Key partners	Who are our Key Partners? Which Key Resources are we acquiring from partners?
Key Activities	What Key Activities do our Value Propositions require?
Key Resources	What Key Resources do our Value Propositions require?
Value Propositions	What value do we deliver to the customer? Which one of our customer's problems are we helping to solve?
Cost Structure	What are the most important costs inherent in our business model? Which Key Resources are most expensive?
Revenue Streams	For what value are our customers really willing to pay? How would they prefer to pay?
Customer Relationships	What type of relationship does each of our Customer Segments expect us to establish and maintain with them? How are they integrated with the rest of our business model?
Customer Segments	Who are our most important customers? For whom are we creating value?
Channels	Through which Channels do our Customer Segments want to be reached? How are we integrating them with customer routines?

Table 1. Sample questions for each BMC category.

Please rate all members of your team on the following criteria:
1. Team meetings: Attendance & promptness in team meetings
2. Quality of participation in team meetings
3. Willingness to accept responsibility
4. Leadership/contribution within one's discipline
5. Contribution outside of one's discipline
6. Degree of cooperation
7. Communication skills
8. Ability to meet deadlines
9. Level of flexibility
10. Has carried one's share of workload

TABLE 2. Items used in the online peer-review process.

The data collected from the status reports and BMCs was then categorized to extract the sources the teams used to validate their hypotheses. We extracted two major categories: (1) First-hand sources and (2) Public sources. First-hand sources included expert or advisor interviews, self-generated surveys, estimations or experiments. Public sources included journal publications, newspaper articles, market research, company websites, or any other written piece of information that was publicly available. We also examined to what extent teams used multiple sources to validate their hypotheses and the general mix of first-hand and public sources cited in their BMCs.

In the next step, the written and verbal exchanges between teams and their stakeholders were analyzed, extracting information on the current position of the stakeholder, and any exchanges between students, advisors and/or experts concerning key issues such as intellectual property management, business model development or next steps.

Finally, our data collection contained peer-reviews to measure students' perceptions of collaborative contributions over two different time points – midway through the course (time 1) and at the end of the course (time 2). For example, the survey asked students to rate each other and themselves on the following categories: (a) Participation, (b) Caliber of contribution, (c) Leadership, (d) Degree of cooperation, (e) Ability to meet deadlines, and (f) Work sharing (see Table 2). Students were asked to rank each item on a 10-point scale, ranging from 1 (poor) to 10 (outstanding). Students were also asked to elaborate if they gave low marks (7 or lower) to any of their team members. We then created a composite score by summing all the items.

RESULTS

Peer-reviews

The peer-review data was analyzed using repeated-measures analysis of variance (ANOVA) [79]. Specifically, our model used a combination of repeated-measures – ***time***– and between-group

	Peer-review item	Time 1 Mean	Time 1 SE	Time 2 Mean	Time 2 SE
1.	Team meetings: Attendance & promptness in team meetings	8.29	0.14	8.53	0.13
2.	Quality of participation in team meetings	8.43	0.13	8.79	0.12
3.	Willingness to accept responsibility	8.69	0.13	8.89	0.12
4.	Leadership/contribution within one's discipline	8.84	0.12	9.01	0.11
5.	Contribution outside of one's discipline	7.50	0.15	7.66	0.15
6.	Degree of cooperation	8.51	0.13	8.91	0.12
7.	Communication skills	8.35	0.14	8.74	0.12
8.	Ability to meet deadlines	8.88	0.08	9.19	0.17
9.	Level of flexibility	8.42	0.09	8.53	0.19
10.	Has carried one's share of workload	8.63	0.10	8.77	0.21
	Composite score of all items	82.61	1.63	87.42	0.96

Table 3. Mean and standard error for each peer-review item.

variables – ***gender*** and ***discipline***. The reliability of the peer-review assessment tool was good, with a Cronbach's α of 0.87. In total, we collected 254 peer-review responses from 46 students, excluding self-evaluations. Students affiliated with the business school (28%) and the school of arts and sciences (35%) account for about two thirds of the class population, followed by students from the engineering (20%) and law school (17%). Table 3 summarizes the means and standard errors for each peer-review item as well as the composite score of all items that was used to conduct the repeated-measures ANOVA. Item scores varied between 7.5 and 8.88 for time 1 (mid-point of class) and between 7.66 and 9.19 for time 2 (end of class).

We found a statistically significant effect of time on peer-review scores (composite), $F(1, 246) = 8.28$, $p = 0.004$. In contrast, no statistically significant effects were found regarding the interaction of time and gender, time and discipline as well as time, gender and discipline (see Table 4)

		SS	df	Mean Sq.	F	Sig.	η_p^2
Composite	Time	1601.82	1	1601.823	8.284	.004**	.033
	Time x Gender	265.18	1	265.181	1.371	.243	.006
	Time x Discipline	98.81	3	32.937	.170	.916	.002
	Time x Gender x Discipline	74.87	3	24.955	.129	.943	.002
	Error(time)	47565.4	246	193.355			

$^{**}p<0.01$

Table 4. Repeated-measures ANOVA for peer-review composite score.

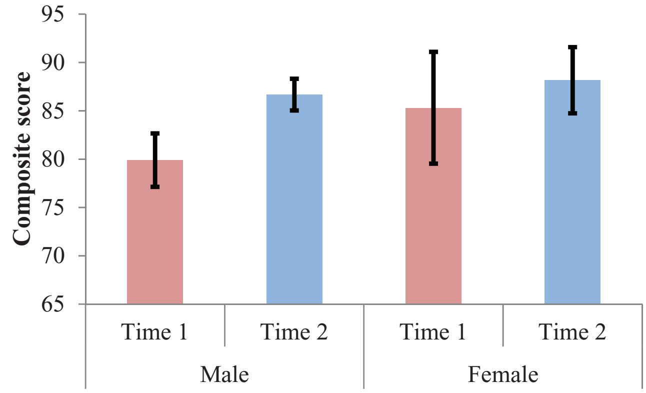

Figure 2. Peer-review composite score for different gender between time 1 and time 2.

Furthermore, the results of the post-hoc tests – using Bonferroni to adjust for multiple comparisons – showed a statistically significant increase in male students' composite scores between time 1 and time 2 (see Figure 2). Peer evaluations for male and female students did not differ significantly.

The post-hoc tests also showed a statistically significant increase for business students' evaluations from time 1 to time 2 (see Figure 3).

Additionally, peer evaluations for students in arts and sciences and law were significantly lower at the end of the class than peer evaluations for engineering and business students (see TABLE 5).

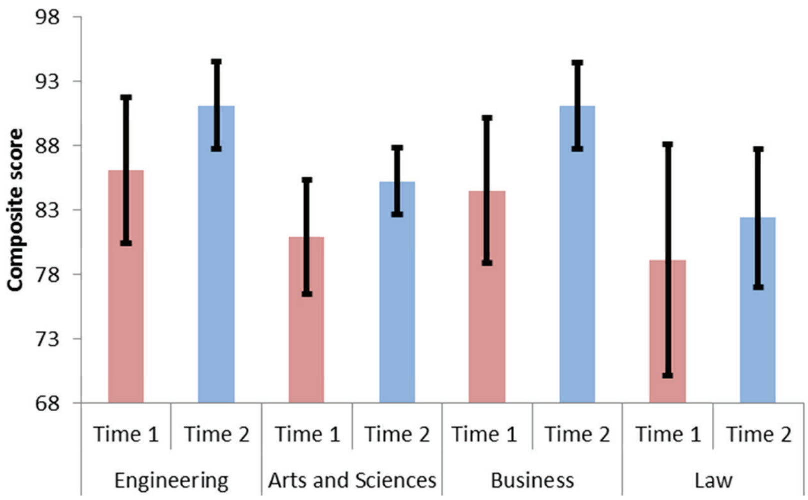

Figure 3. Peer-review composite score for different disciplines between time 1 and time 2.

Mean differences	Time 1	Time 2
Engineering - Law	6.97	8.73*
Business - Law	5.41	8.71*
Engineering - Arts and Sciences	5.15	5.88*
Arts and Sciences - Business	–3.60	–5.86*
Arts and Sciences - Law	1.82	2.85
Engineering - Business	1.55	0.02
*significant ($p < 0.0083$)		

Table 5. Multiple comparisons between peer-evaluation scores between different academic programs.

Status Reports And Business Model Canvases

In the second part of our analysis we examined the weekly reports of teams NanoPlast, EnEff, SiNano and WaterPur, extracting the number and category of stakeholders students engaged with. Over the course of the 10-week class, all four teams contacted a total 198 experts from a variety of fields and job functions. However, the number of reported contacts varied substantially between the teams. For example, SiNano reported a high of 51 established contacts; whereas NanoPlast's contact list only included 13 experts (see Figure 4).

Based on job function, we then separated the reported contacts into six different categories: (1) Technical, (2) Law, (3) Entrepreneurial, (4) Venture capital, (5) Management, and (6) Other. Two separate coders were employed with an inter-rater reliability of 85%. Contacts with a technical background included engineers and scientists of all majors. Contacts with a background in law

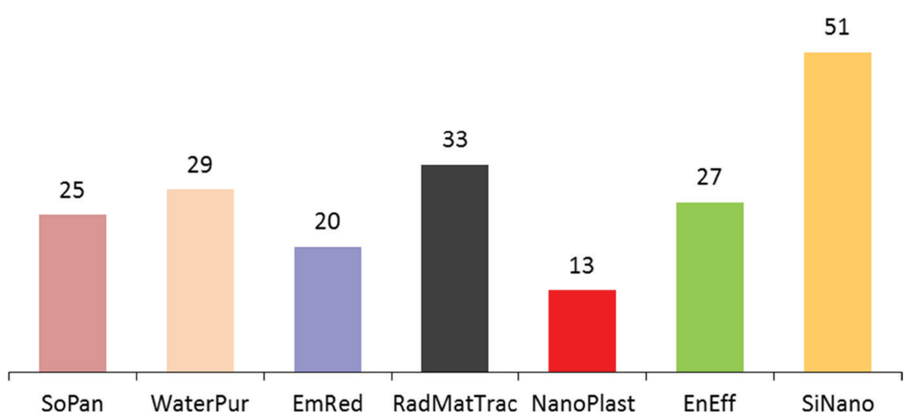

Figure 4. Number of established contacts extracted from weekly status reports.

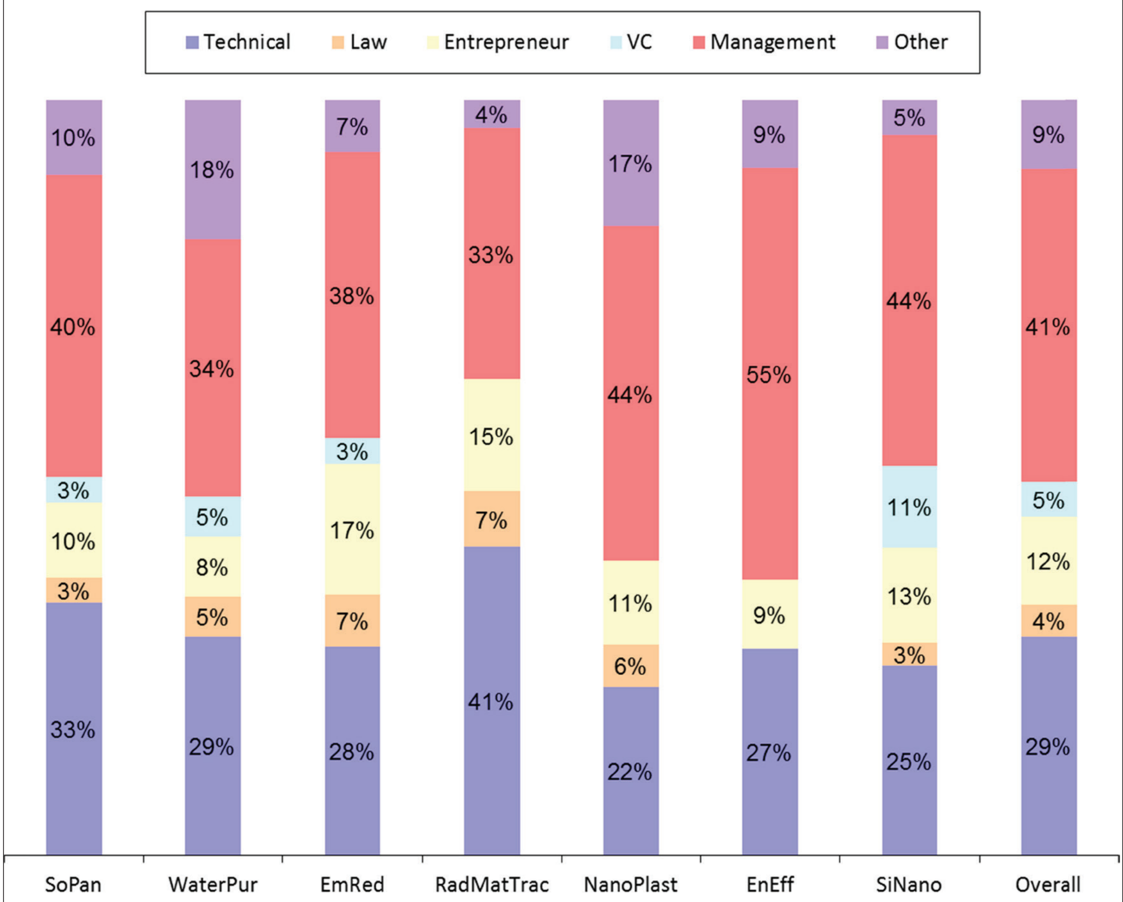

Figure 5. Composition of team contacts.

included lawyers specializing in intellectual property, environmental and corporate law. Contacts with a background in entrepreneurship included entrepreneurs – one-time and serial. Contacts with a background in management included middle- and C-level managers (e.g. CEOs, CFOs, and COOs). Contacts classified as *other* included analysts, policy experts and students. The results indicate that the majority of contacts that teams established fell into the management (41%) and technical category (29%) (see Figure 5). The data also shows that lawyers and venture capitalists accounted for the smallest share in the team's contact portfolio.

Afterwards, we examined the teams' hypothesis validation process and found that the seven teams generated between 30 (EmRed) – 55 (SiNano) hypotheses in all nine BMC dimensions (see Table 6). The majority of the teams validated more than 50% of their hypotheses (SoPan, WaterPur, EnEff, and SiNano), whereas teams EmRed, RadMatTrac, and NanoPlast fell below that threshold.

	Generated	Validated (in %)	Invalidated (in %)
SoPan	42	32 (76)	10 (24)
WaterPur	37	22 (60)	0
EmRed	30	12 (40)	0
RadMatTrac	29	3 (10)	0
NanoPlast	32	9 (28)	1 (3)
EnEff	27	15 (55)	7 (26)
SiNano	55	32 (58)	12 (22)
Overall	**252**	**125 (50)**	**30 (12)**

Table 6. Hypotheses generated, validated and invalidated through Lean Launch Lab.

The data also showed that all seven teams utilized first-hand and published sources with varying degree. ***SoPan***, for example, supported the vast majority of their hypotheses through first-hand sources such as expert interviews (see Table 7). In contrast, ***RadMatTrac*** validated their business model, using information from published studies or reports.

Moreover, all seven teams used at least one source to validate their business model hypotheses. However, teams varied in the use of multiple sources of validation. For example, ***EmRed*** and ***SiNano*** validated/invalidated more than half (60% and 83%, respectively) of their hypotheses using multiple sources, whereas ***RadMatTrac*** only used one source (see Figure 6).

Subsequently, we examined the interaction between students and experts in more detail, to get a more complete picture of how students construct their business models. For example, team WaterPur interviewed an industry expert to ascertain how they can convince municipalities to implement their technology. The expert explained that *"politics play a role in getting technology implemented*

	First-hand	Published	Both
SoPan	77%	13%	10%
WaterPur	74%	26%	0%
EmRed	58%	8%	33%
NanoPlast	60%	15%	25%
RadMatTrac	34%	66%	0%
EnEff	53%	32%	15%
SiNano	32%	23%	45%
Overall	**60%**	**25%**	**15%**

Table 7. Source categories for validated/invalidated hypotheses.

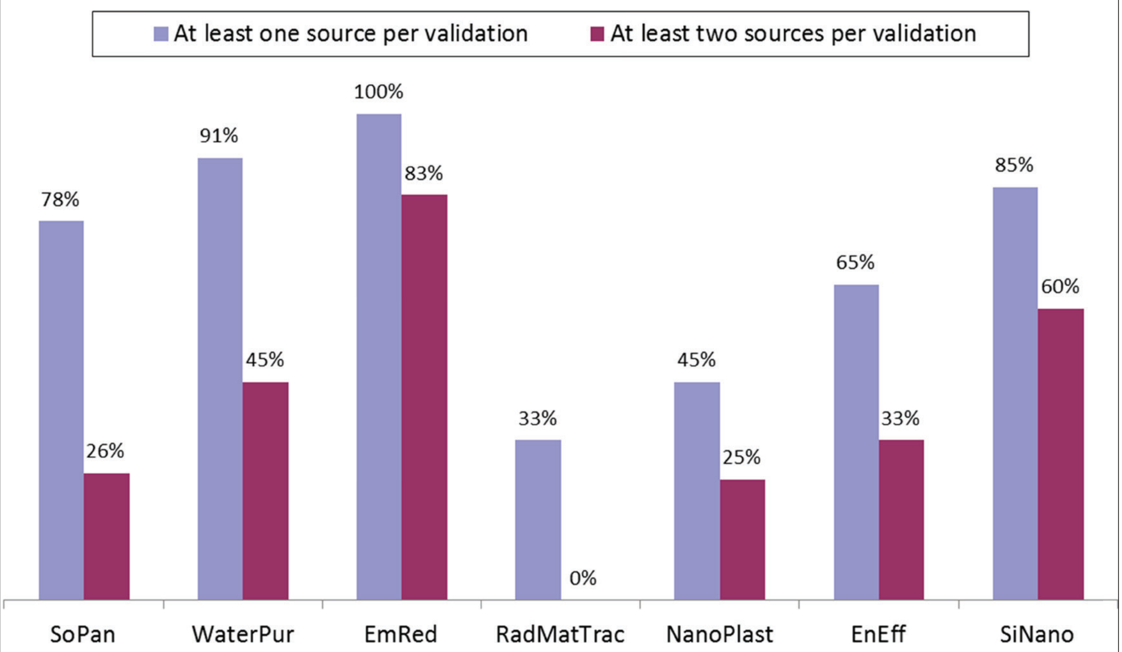

Figure 6. Share (in %) of hypotheses validated or invalidated by one or more or two or more sources.

[and] *that they might want to get a local firm that will be involved in providing the solution to the municipality"*. Following the interview, the team incorporated that piece of information into the Channels category of their BMC arguing that they have to "*sell through a reputable engineering firm (ex: Hinker and Clover*[1]*) who will outfit our material so that it can be optimized for specific municipal wastewater treatment plants, and/or industrial plants for advanced oxidation".* On the other hand, team EmRed provided an example of triangulating multiple sources of evidence such as market research, expert interviews and self-generated calculations to validate parts of their business model. EmRed hypothesized that their revenue stream should consist of a basic and a premium account. They argued that "*…throughout* their ***market research***, they *consistently received skepticism that retailers would be willing to pay for carbon calculations given that SmartWay*[2] *provides this same service for free.* Consequently, they would offer a "freemium" model that would allow *"a retailer who is only concerned about emissions to use EmRed to receive its carbon calculation for free, similar to SmartWay."* Retailers that were interested to optimize a variety of inputs such as carbon footprint, shipping times and costs could sign up for the premium account. To further develop a pricing model, EmRed

1 Name altered

2 SmartWay is an EPA funded initiative to estimate transportation emissions free of charge.

BMC Category	Hypothesis	Validation (Source)
Key partners	*"We need partnerships to make our prototype"*	We will partner with companies like LifeSaver/R.E.I. for the water bottle application, and companies like WaterHealth to swap current disinfection techniques (U.V., chlorine) with ***WaterPur***. (Interview)
Value proposition(s)	*"Increase asset utilization"*	"…34% of shippers use internal TMS systems. Therefore, increasing the number of players who are filling empty miles through ***EmRed*** will help all customers to optimize asset utilization (Market research & expert interview)
Customer segment	*"Municipalities and Wastewater Treatment"*	***WaterPur*** is less expensive, less hazardous, and has a very long life span (Patents)

Table 8. Examples of validated hypotheses for different BMC categories.

consulted two industry experts that "*indicated that companies like company A would be willing to pay around $30–$40*[3] *per month for this sort of service. Smaller companies would only be willing to spend that much per year (John*[b] *from company B), and much larger companies who engage in a lot of transportation and shipping spend far more than that on current TMS (Michael*[b] *from company C)."*

After synthesizing all the inputs, EmRed decided to "*charge a commission based on estimated $ saved on freight for the year*". EmRed developed their pricing model such that they would "*charge a 3%*[d] *commission based off of a goal target of 0.5%*[d] *shipper freight savings per year.* This would help them "*navigate the issue of retailers not wanting to pay a fairly high fixed fee (see excel sheet model for details). If we are able to gain a 99%*[d] *adoption rate by small refrigerated shippers (our initial target market), we believe this would generate annual revenue of $100*[d]*."* Table 8 provides additional examples of validated hypotheses and their sources for three BMC categories.

CONCLUSION AND FUTURE WORK

The first goal of our research study was to examine students' collaborative skills over time. The results of the peer-review data showed that students' collaborative contributions – measured through the composite score of all peer-review items - improved over time. Furthermore, the variance of the composite scores declined from time 1 to time 2 with response rates staying the same, adding to the statistical robustness of our study. The results of the post-hoc tests were twofold. Firstly, male students' evaluations improved significantly, more so than female students, who started out at a higher level of collaborative contributions. The differences in composite scores between male and female students, on the other hand, showed no significant differences for any of the evaluation periods.

3 Number altered

Secondly, engineering and business students were evaluated significantly higher than their peers from arts and sciences and law at the end of the class. Several explanations exist. The bulk of the class deliverables were focused on the technical feasibility as well as the business model, placing students from arts & sciences as well as law at the functional periphery of the team. Another aspect to consider was the difference in class schedules between students of the four schools. Students from business and engineering were on a more similar schedule than students from arts & sciences and law. These findings indicate how important it is for instructors and administrators to consider macro (e.g. scheduling) as well as micro factors (e.g. implicit and/or explicit role assignment) in their course design.

Based on the experiences with our peer-review assessment tool we also found that there are few, if any, targeted assessment tools that can accurately measure interdisciplinary collaboration, and the role it plays in the process of entrepreneurial learning and new venture formation. For example, in a preliminary review of students' reflections of their team experiences, we found information on role assignment with respect to entrepreneurial tasks: *"…certain people came to the fore and really stepped up to the challenge (Student A for really structuring our BMCs; Student B for market research; Student C for overall organization and financial plans; Student D for developing our MVP; Students E & F for working on the PPPs and BMC iterations; me for preparing supporting documentations)"* as well as information about teamwork qualities (or the lack there of) such as equal work share and commitment to the task: *"…at a certain point in the semester, I did not personally feel comfortable even assigning him discrete tasks, because he was so out of touch with the business plan…he lacked initiative and I would not choose to work with him in a group again. I would happily work on a team with everyone else again."* This points to the fact that team-based instruction needs to develop tools that capture team processes more accurately.

The second goal of our research study was to explore how entrepreneurs in the making, engage with experts and advisors to assess and construct their new business models. The results from our status reports and the business model canvases contained a variety of different technological, legal and economic aspects concerning the teams' entrepreneurial ventures. Specifically, the data from the business model canvases showed that teams used a varying degree of first-hand (expert interviews or estimates) and published resources (studies or reports), in their process of hypothesis validation. There is a set of possible explanations including uncooperative project partners, lack of experts and published articles due to the novelty of the technology, and inconsistent team processes that we will need to further examine.

We also faced some issues with regards to the use of intellectual property provided by our project partners. For example, team NanoPlast reported after an initial conversation with their project partner concerning the acquisition of licensing rights that *"typical license deals involve an upfront fee and continuing royalties"*. However, *"for startups, project partner A will accept equity in place* *of the fee with a nonvoting chair on the company board"*. Although, their project partner initially granted the team permission to use two patents in a business plan competition, *"the permission to use the second patent got revoked in week 8 of the class."* This issue demonstrates the challenges that entrepreneurship classes and programs face when acquiring project partners for student teams. As a result, some of the faculty suggested letting students develop their businesses based on their own intellectual property, but we found that building relationships with project partners can offer students learning opportunities and networks that can go beyond the classroom.

Overall, our results suggest that students had the opportunity to gain unique insights into emerging industries and experience a real business environment in which they can engage in entrepreneurial learning. In addition to exchanging ideas with entrepreneurs, business leaders, lawyers, scientists and engineers, students were able to hone important skills such as teamwork, business model development, and opportunity recognition. In summary, we strongly support the use of team-based entrepreneurship classes as they provide students with the ability to engage in future entrepreneurial activities and work in interdisciplinary teams. We also see many fruitful avenues for research and pedagogical innovation. Specifically, we would like to expand existing research on role adoption [64,80], social sensitivity [25,81] as well as experiential learning theory [82–84] to help develop more effective research and teaching tools in entrepreneurship education.

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