# A hands-on DSP project mixing Entrepreneurial and technical concepts

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**ABSTRACT**

Nowadays, industry is demanding engineers with entrepreneurial background. At Ohio Northern University, entrepreneurship mindset is becoming a crucial part of the curriculum. This paper suggests a hands-on DSP project that introduce students to entrepreneurial concepts while covering most of the technical material they studied in the class. Through this project students will learn how to construct and effectively communicate a customer appropriate value proposition. They will also learn how to apply critical thinking to solve practical problems.

Towards the end of the semester, students are provided with an artificial bid on a product that they have to design within certain realistic constraints including cost, material and size. Their task is to answer the bid with a report that shows enough evidence that they can generate the correct prototype that can satisfy the customer needs.

**PROJECT DESCRIPTION**

The project requires students to form teams, or fictitious companies, comprised of two to three members. The task is to respond to a Request for Proposal (RFP) that requires the design of an embedded DSP processor that can denoise and equalize the output of an electrical guitar, as well as displaying its frequency spectrum on an LCD screen. In the written proposal, teams must translate the given customer specifications to engineering specifications or requirements, research the problem, pick the embedded platform, list the extra required materials, show total cost including labor, illustrate the filter design and implementation, verify the designed filters through simulation, establish a detailed testing plan, investigate proper device housings, and propose a time schedule for delivery.

The request for proposal was as follows:

Mr. Bob owns an electric guitar company. His guitars are made of high quality materials but the pickups suffer from a fundamental problem. Their output is somehow noisy. His picky customers are starting to detect this and are giving bad reviews about his guitars online. If these reviews spread they will soon have devastating effects on his business. He is looking for a quick solution to his problem. He wants to add a piece of hardware at the output of his guitars that can filter this noise out. He is looking for a small embedded solution that can operate in real time and does not consume a lot of power. His company produces 50 guitars on a daily basis and his guitars do not cost a lot, so he is looking for a cheap solution.

Mr. Bob is not a technical person. He is looking for outside help. He has a typical noise sound clip from a sample guitar. He will select the company that can de-noise that clip perfectly and provide him with the cheapest and most compact design that consumes the least amount of power. Mr. Bob will give preference for companies who can use the same embedded system to provide the customers with real-time display of the signal spectrum.

Another, attractive feature will be a digital equalizer that can boost or attenuate in real-time the frequencies within the following ranges: Bass, mid-Bass, Midrange, Upper Midgrange, and High End.

## SAMPLE STUDENT WORK

All students in the class completed the required tasks based on the RFP. The list of deliverables included:

- Block diagrams
- Filters specifications, design and simulation
- Bill of material
- Cost analysis
- Delivery time
- Testing plan
- High level schematic of the board including the embedded platform and display screen
- Specifications of the A/D and D/A converters
- Different device connectivity.

An example of the students' work that shows the required deliverables is discussed next.

Students started first by analyzing the noisy sound clip provided by Mr. Bob. Figure 1 below shows the Fast Fourier Transform (FFT) of the clip.

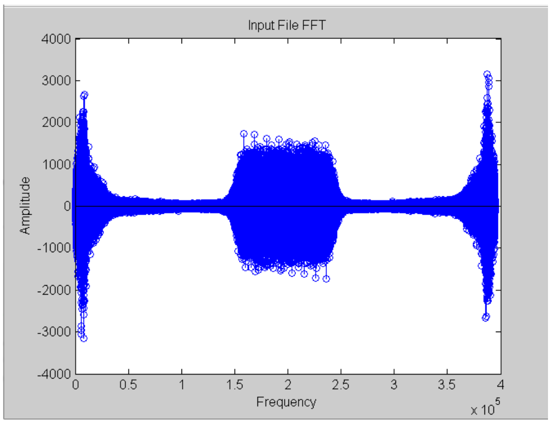


**Figure 1.** FFT of the noisy sound clip

Based on the analysis, they realized that the in-band noise is in the high frequency range and designed accordingly a digital Low Pass Filter (LPF) to get rid of the noise. They then simulated the filter using the noisy sound clip as an input and verified the quality of the output file qualitatively by listening and quantitatively by checking the FFT of the output as shown in Figure 2.

Next students focused on designing a digital equalizer. To design the equalizer students had to drive specs for the different filters. An example of the derived specs for the denoising filter and the equalizer are shown in Table 1. The table also shows the cost of every filter in terms of adders, multipliers and flip flops.

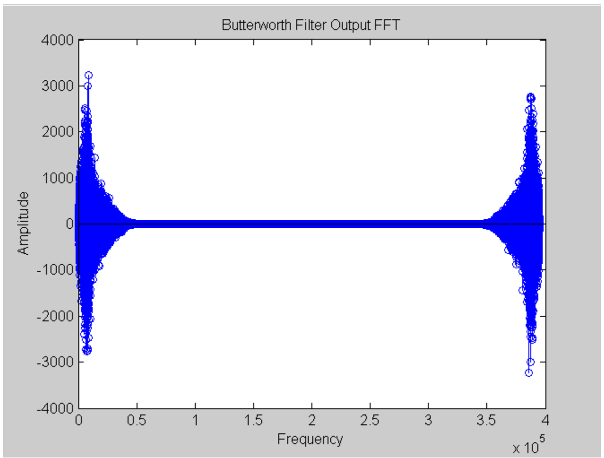


**Figure 2.** FFT of the denoised output file

**Table 1.** Filter Specifications

| ***Lowpass Filters*** | **Type** | **fpass (Hz)** | **fstop (Hz)** | **StpAtten (dB)** | **Order** | **Flip Flops** | **Adders** | **Mults** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Denoising Filter | Butterworth (IIR) | 4000 | 4500 | 10 | 15 | 15 | 30 | 31 | | |
| Bass Filter | Chebyshev Type 2 (IIR) | 140 | 160 | 10 | 5 | 5 | 10 | 11 | | |
| ***Bandpass Filters*** | **Type** | **fstop1 (Hz)** | **fpass1 (Hz)** | **fpass2 (Hz)** | **fstop2 (Hz)** | **Stp1,2Atten (dB)** | **Order** | **Flip Flops** | **Adders** | **Mults** |
| MidBass | Chebyshev Type 2 (IIR) | 70 | 140 | 400 | 500 | 10 | 6 | 6 | 11 | 12 |
| MidRange | Chebyshev Type 2 (IIR) | 350 | 400 | 2600 | 3000 | 10 | 10 | 10 | 19 | 20 |
| UpperMidRange | Chebyshev Type 2 (IIR) | 2000 | 2600 | 5200 | 6000 | 10 | 6 | 6 | 11 | 12 |
| HighEnd | Chebyshev Type 2 (IIR) | 4800 | 5200 | 20000 | 22000 | 10 | 12 | 12 | 24 | 25 |

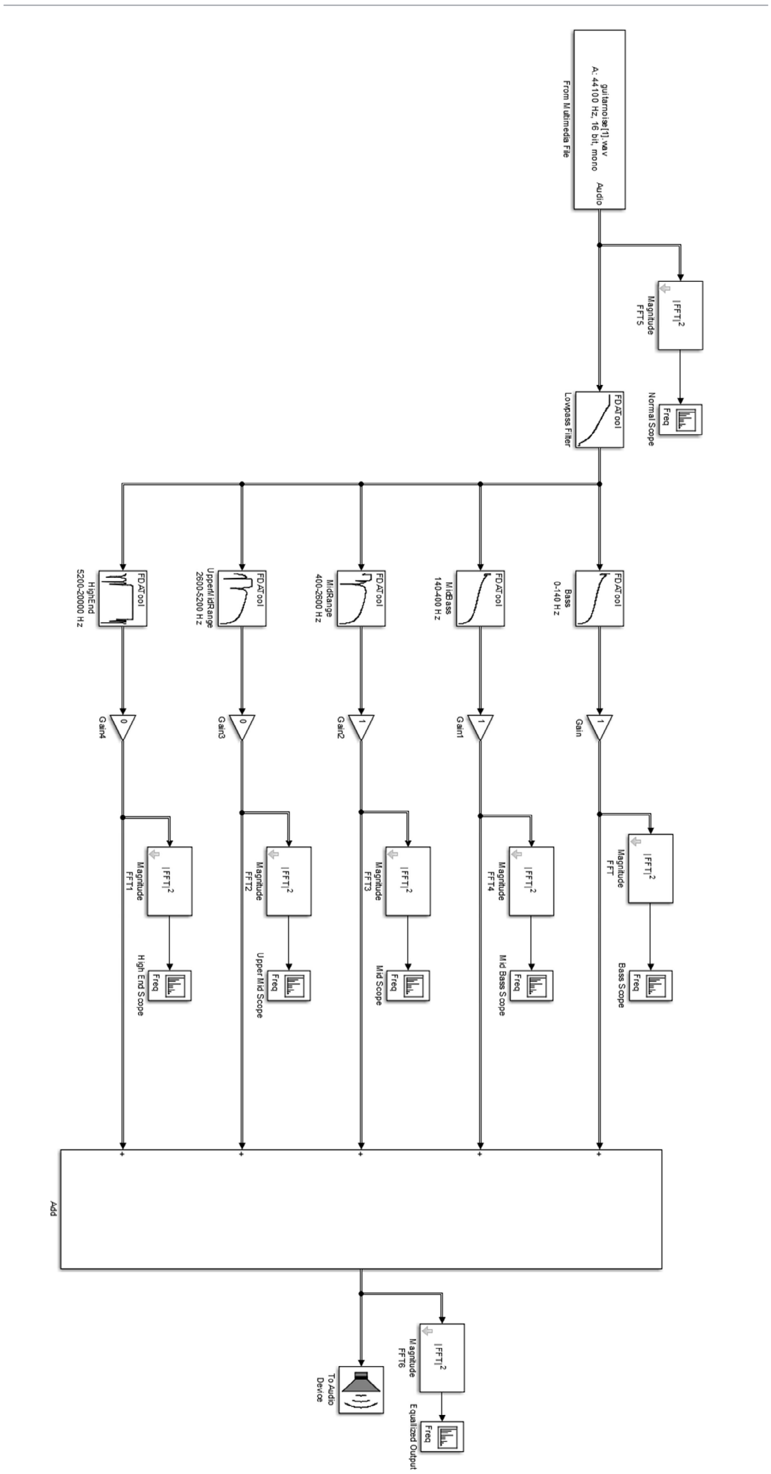


**Figure 3.** Block Diagram of Denoising and Equalizer Filters

Next, students worked on finding the energy of the signal at the output of the different equalizing filters. To find the energy of the signals they had to pick a particular time window duration. Typically, LCD screens got updated at a rate of 30 frames per second. Hence, the time window should not be larger than 1/30 seconds. The samples at the output of each filter were squared and added during that time to find the energy. The energy is displayed in dB range.
After finishing all these tasks, students simulated their digital design in Simulink. While using Simulink they needed to take the effect of quantizing the filter coefficients into effect. Most students end up picking 8-bits of fraction for the different coefficients. Figure 3 shows an example snapshot from Simulink showing the different block diagrams of the digital design.

Then, students had to worry about different design components that included picking the right anti-aliasing analog LPF, an embedded platform with the necessary hardware to implement the project, A/D and D/A components, and LCD screen. Figure 4 shows a snapshot of these choices.

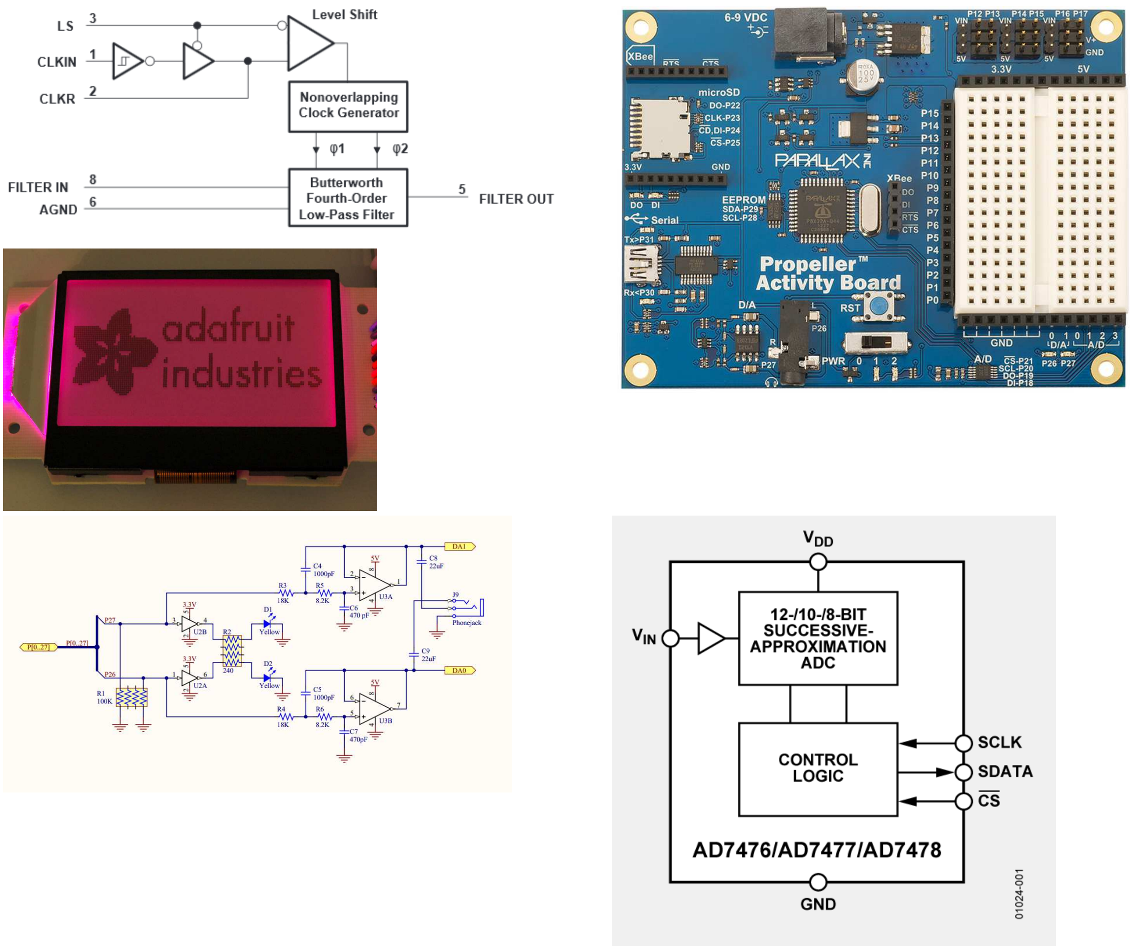


**Figure 4.** A snapshot of different design components.

The following task was to sketch a high level schematic of the project, as shown in Figure 5.

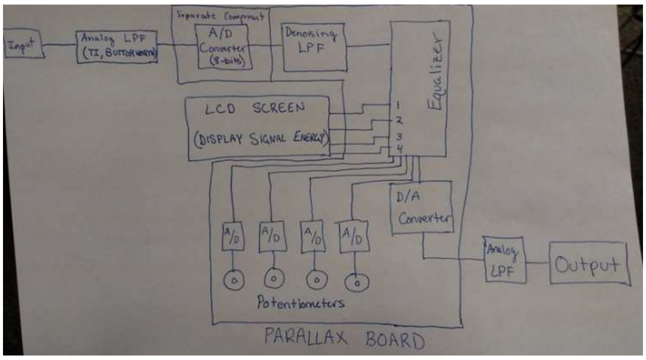


**Figure 5:** A high level schematic of the project

After finalizing the technical part of the proposal, students focused on entrepreneurial concepts such as driving Bill Of Material (BOM) for one day of production, calculating a cost analysis that includes the external expenses, estimating the delivery time and showing their testing plan. An example of BOM, cost analysis and testing plan is shown in Tables 2, 3 and 4 respectively.

**Table 2.** Bill of Materials Per Day

| **Component** | **Model (Mouser)** | **Description** | **Quantity** | **Price Per Unit** | **Total Price** |
|---|---|---|---|---|---|
| Analog low pass filter (Butterworth) | **Mouser** 595-TLC14ID (Texas Instruments) | Low pass filter for external design | 2 x 50 = 100 | $2.53 | $253.00 |
| Potentiometers | **Mouser** 72-P16SNP223MAB15 | Allows control over device | 4 x 50 = 200 | $9.11 | $1,822.00 |
| Display | Adafruit ST7565 | Graphic LCD Display Board | 1 x 50 = 50 | $16.16 | $808.00 |
| Board | Propellor Activity Board | 8-Core microcontroller | 1 x 50 = 50 | $37.49 | $1,874.50 |
| 9V Battery | Duracell | 9-V alkaline battery | 1 x 50 = 50 | $0.95 | $47.50 |
| A/D Converters | Analog Devices AD7478 | 8 bit A/D Converters | 50 | $1.00 | $50.00 |
| | | | | **Total Price** | $4,855.00 |

**Table 3.** External Expenses

| | Description | Quantity | Price per Month |
|---|---|---|---|
| **Labor Expenses** | Salary for Technicians | 3 x $10.00/hr (6 hrs/day) | $5,400.00 |
| **Shipping Expenses** | Daily pick and delivery service | 1 box at $10/day | $300.00 |
| **Property Rental** | Warehouse Rental | Per day | $1,000 |
| **Insurance, License, and Permit Fees** | Insurance fees and permit fees in Ohio | Per day | $450.00 |
| **Engineering Labor** | Design, Prototyping, Testing, etc. | $104/hr | $8,333.33 |
| | | **Total Price** | $15,483.33 |

## ASSESSMENT OF STUDENTS WORK

The grading rubric used to assess the quality of the written proposals is shown in Figure 6. It covers both technical and entrepreneurial concepts. Students work was also assessed based on two entrepreneurial outcomes that were set by the Keen foundation[1]:

- Keen outcome 2: “apply critical and creative thinking to ambiguous problems”
- Keen outcome 3: “construct and effectively communicate a customer appropriate value proposition”

The results of that assessment are shown in tables 5 and 6, respectively. Based on those assessment keen entrepreneurial concepts were generally satisfied.

Finally, students were surveyed at the end of the project to collect their feedback and analyze it for future improvements.

The questionnaire included the following statements:

1. The project enhanced my understanding of the course
2. The project enhanced my expertise in hardware platforms
3. The project exposed me to entrepreneurship mindset
4. The project taught me how to effectively work in a group setting
5. The project exposed me to practical issues in an engineering design problem
6. If I were to take the course again, I would recommend having more projects.

Students were asked to rate them between strongly disagree, disagree, neutral, agree, and strongly agree. Table 7 summarizes the results of that survey. The weighted average of their answers is above 3. Hence, students in general were either neutral or agree that the project satisfied its outcomes.

They also left the following comments:

- should have started earlier in the semester
- More time and explanation

Based on these comments, next year the project will be introduced at the beginning of the year and integrated with the lab component of the class.

**Table 4.** Prototype Test Plan

| Sr. | Requirements | Components | Description |
|---|---|---|---|
| **1** | Benchmarks | Assembled Prototype | Come up with benchmarks to meet expectations from buyer (such as speed of filtering, power consumption, etc.). |
| **2** | Device is Correctly Coded | Propeller Activity Board | Using C++, make sure each component on the board is correctly coded. |
| **3** | Ensure various inputs are correct | Input signal connection | Testing the input signal connection to the device using spectrograms. |
| **4** | Ensure output is correct | Output signal connection | Testing the output signal connection to the device using spectrograms. |
| **5** | Test Equalizer Code | Adafruit LCD Screen | Using spectrograms, analyze each section using attenuation and amplification. |
| **6** | Test full prototype through Guitar | Assembled Prototype | Testing the entire prototype on a guitar, to ensure quality and ability |

**Written proposal Rubric**

| Category | Does Not Meet Expectations | Developing | Meets Expectations | Proficient |
|---|---|---|---|---|
| **Overall quality of the report** | Thesis statement is unclear or absent. Writes paragraphs that are underdeveloped, with topic sentences that are missing or unsupported. Writes sentences that are unclear or indirect (pts 0-4) | Provides a thesis statement that is somewhat developed. Writes paragraphs that are developed inconsistently, with topic sentences that are present, but not fully supported. Writes sentences that are occasionally unclear, indirect or grammatically incorrect. (pts 4-8) | Provides a thesis statement that is generally clear. Writes paragraphs that are generally well-developed, with topic sentences that are present and supported. Writes sentences that are generally clear, concise, and direct. (pts 8-12) | Provides a strong, clear thesis statement. Writes paragraphs that are well-developed, with strong, focused topic sentences that are fully supported. Writes sentences that are consistently clear, concise, and direct and grammatically correct. (pts 12-15) |
| **Deliverables related to manufactura bility** | All of the following are missing or wrong: Block diagram, filter specs and design, simulation(pts 0-4) | A large portion of the following list is not available in the report: Block diagram, filter specs and design, simulation(pts 4-7) | Most of the following list is presented correctly in the report: Block diagram, filter specs and design, simulation(pts: 7 - 10) | The report contains all the necessary deliverables that gaurantee the correct operation of the design (pts 10-13) |
| **Deliverables related to cost estimate and delivary** | All of the following are missing or estimated wrongly: Bill of material, cost analysis, and delivary time (pts: 0-3) | A large portion of the following list is either missing or estimated wrongly: Bill of material, cost analysis, and delivary time (pts: 3-6) | The following list is present but there is some minor mistakes in the estimation process: Bill of material, cost analysis, and delivary time (pts: 6-9) | The report estimates the cost and deliveray time correctly (pts 9 -12) |
| **Design functionality** | All of the following are missing or wrong: High level schematic of the board including the embedded platform and display screen, specs of A/D and D/A converters,device connectivity, testing plan(pts 0-3) | A large portion of the following list is not available in the report: High level schematic of the board including the embedded platform and display screen, specs of A/D and D/A converters,device connectivity, testing plan(pts 3-5) | Most of the following list is presented correctly in the report: High level schematic of the board including the embedded platform and display screen, specs of A/D and D/A converters,device connectivity, testing plan(pts 5-8) | The report contains all the necessary deliverables that gaurantee that the board will function correctly (pts 8-10) |

**Figure 6.** Written proposal rubric

## CONCLUSION

A number of attempts have been made in literature [2,3, and 4] to introduce entrepreneurial concepts to engineering students at the freshman or senior level. However, it is always challenging to teach these concepts at the sophomore and junior levels where most of the technical content of the curriculum is covered. This paper describes an attempt to bridge this gap through projects that cover both technical and entrepreneurial concepts.

**Table 5.** Results of keen outcome 2 assessment

| Construct and Effectively communication of a customer appropriate value proposition | | | | |
|---|---|---|---|---|
| | Does not meet expectation | developing | Meet expectation | Proficient |
| Section 1 of 3: Problem identification | | | | |
| Identifies key issue(s) and converts to a problem statement | 2 | 0 | 13 | 10 |

| | | | | |
|---|---|---|---|---|
| Considers the situation from multiple perspectives | 2 | 0 | 13 | 10 |
| Section 2 of 3: Research and analysis | | | | |
| Demonstrates ability to identify and evaluate information | 2 | 0 | 15 | 8 |
| States plausible reasoning for position or actions described | 2 | 0 | 15 | 8 |
| Analyzes information using appropriate conceptual framework/tools | 2 | 0 | 15 | 8 |
| Section 3 of 3: Solution development | | | | |
| Displays ability to explore alternate options to the identified problem | 2 | 0 | 23 | 0 |
| Makes convincing arguments for recommended option, aligned to the given context | 2 | 0 | 11 | 12 |

**Table 6.** Results of keen outcome 3 assessment

| Construct and Effectively communication of a customer appropriate value proposition | | | | |
|---|---|---|---|---|
| | Does not meet expectation | developing | Meet expectation | Proficient |
| Section 1 of 3: Written Communication | | | | |
| Overall Organization | 2 | 0 | 9 | 14 |
| Paragraph Development | 2 | 0 | 9 | 14 |
| Format and Style | 2 | 0 | 9 | 14 |
| Written Language Mechanics | 2 | 0 | 9 | 14 |

**Table 7.** Results of student survey

| | SD | D | N | A | SA | |
|---|---|---|---|---|---|---|
| Weight | 1 | 2 | 3 | 4 | 5 | Average |
| S1 | 1 | 1 | 1 | 15 | 6 | 4 |
| S2 | 1 | 3 | 7 | 10 | 3 | 3.5 |
| S3 | 1 | 2 | 8 | 8 | 2 | 3 |
| S4 | 1 | 0 | 6 | 13 | 4 | 3.8 |
| S5 | 1 | 1 | 2 | 15 | 5 | 3.9 |
| S6 | 0 | 2 | 10 | 7 | 5 | 3.6 |

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[4] E. L. Wang, and J. A. Kleppe. "*Teaching Invention, Innovation, and Entrepreneurship in Engineering*," Journal of Engineering Education, vol. 90, issue 4, pp. 565-70, 2001.