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Research Article

A gifted and talented middle school material science investigation: utilizing engineering practices to develop sustainable and benign particleboard

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Abstract

Gifted learners are often intellectually curious and require meaningful learning opportunities. This engineering investigtion fosters curiosity while also generating useable knowledge that connects to global issues through a STEM lens. This engineering exercise presents a valuable experience for gifted learners because it not only fosters creativity and is environmentally relevant, but it also compels students to develop and practice academic competencies. This investigation is designed to harness most gifted learners' strong sense of empathy and heightened sense of justice to spawn useable knowledge that can help inform decisions and actions today and in the future. Specifically, the investigation will have gifted students determine if cellulose nanofibrils (CNF) are suitable as a non-toxic, environmentally benign adhesive for the construction of particleboard. Students become heavily invested in the project when they know they are working towards a more sustainable and safe product. In this study, the case study method was used. The project work conducted with middle school gifted students was handled as a case study, focusing on the process and outcomes. Students are able to meet many of the Next Generation of Science Standards (NGSS) enginerring performace expectations, complete aspects of all of the science and engineering practices, explore several engineering disciplinary core ideas, and consider several crosscutting concepts. This project can be fine-tuned to best meet the needs of any gifted student. This investigative approach incorporates science and engineering practices and encourages students to combine their previous and new science content knowledge with procedural knowledge in relevant ways. Gifted students gain valuable STEM experiences and use novel science equipment to solve a real world problem. This activity exercises students' executive functions for problem solving, organizing, and develops skills including the ability to interpret data and draw pertinent conclusions. The next step in this research is to use pre and post student surveys to quantitatively show the impact of this engineering investigation on improving science and engineering practices, attitudes, content knowledge, and to see how it may influence authentic STEM research projects.

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Introduction

As a middle school grade level and gifted and talented science teacher, the lead author, Vassiliev, is fortunate to spend her summers as a United States Department of Energy RET (research experience for teachers) with the Hub & Spoke SM^{2}ART (Sustainable Materials & Manufacturing Alliance) research collaborative between the Advanced Structures and Composites Center at the University of Maine and the Department of Energy's Oak Ridge National Laboratory Alliance for Renewable Technologies. This RET opportunity allows her to be surrounded by passionate real world problem solvers who want to share their research in the hopes of igniting similar passions in middle school students.

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When teachers are provided the opportunity to spend significant time focusing on authentic scientific studies, they can develop a much more sophisticated understanding of the nature of science and better appreciate teaching through inquiry and not just approach it as a body of knowledge (Vassiliev, et al., 2020). According to Crawford (2012), when *"teachers are given opportunity to participate in authentic science, they demonstrate greater confidence in enacting inquiry-based instruction in their classrooms; their enthusiasm, in turn, increases, and we see evidence of motivated and engaged students in their classrooms (p. 38)"* Authentic science research provides teachers the background they need to better connect research experiences to the Next Generation of Science Standards' disciplinary core science and engineering practices (NGSS, 2013) while students are immersed in topical science and engineering practices.

Kaplan (2022) found that inquiry and the ability to think independently were the most important learning-to-learn skills (p. 6-7). According to Vassiliev et al., (2020) "*If science is taught without inquiry, you cannot reasonably expect students to ask profound and thoughtful questions, form inspiring and deliberate hypotheses, conduct methodical experiments, decide which measurements to collect, and make connections and construct meaning in the world (p. 9).*" If we amplify the ideas of STEM related inquiry projects we start to modify the nomenclature of inquiry to science and engineering practices. The description of practices encompass more than the word inquiry. When students are engaged in science and engineering practices *"they use the discourse of science and they work with scientific representations and tools. In this way, conceptual understanding of natural systems is linked to the ability to develop or evaluate knowledge claims, carry out empirical investigations and develop explanations (Michaels, et al., 2008, p. 34)."*

Gifted and talented students and/or first-time science fair participants require a tangible reason that resonates with them before they would consider choosing to invest their time in an esoteric undertaking. Superficially, material science research might not appear to be much of a hook to gain the attention of young students. However, if students are exposed to how sustainable materials have the ability to save energy, reduce waste, and improve safety then the idea of making a difference or creating change becomes the motivator that can ignite the middle school students' imagination. These points make such a project "*proactively responsive to the learner and his or her world (Tomlinson et al., 2009, p. 2),*" an important component of effective science curriculum. In addition, problem-solving opportunities are an essential component of learning for gifted students: they require a more sophisticated curriculum and they must be continuously challenged (Gavin et al., 2007; Graffam, 2006). By investigating real-world projects with tangible and positive outcomes, students can be engaged in science and engineering practices while also developing their own sense of altruism (Chase, 2015).

Importance of Study

According to Amini et al., (2017) "*particleboard is a wood composite panel typically manufactured from discrete wood particles combined with a resin or binder under heat and pressure. The resins used in particleboards are mostly made up of formaldehyde-based adhesives (p. 4093).*" Human concerns for the off gassing of formaldehyde are well documented (Frihart, *et al.* 2021). Off gassing is the process of when harmful chemicals from furnishings and finishes are emitted into the air over time (Gray, 2020). Some of the detrimental affects of formaldehyde exposure are breathing problems or irritation of the eyes, nose, throat, or skin. Long-term formaldehyde exposure can also cause cancer (*Formaldehyde and Your Health | ATSDR*, 2018). This real world problem is the catalyst to hook gifted students into investing their time and cognitive abilities into providing a possible remedy to this engineering design challenge.

This article presents a middle school scientific and engineering investigation that was developed to challenge students' problem solving skills and get them to produce scientifically sound results while using sophisticated but simple tools in the laboratory. The investigation employs the critical issue of the need for safe particleboard binders as a motivating factor. Critically, the investigation was designed to encompasses several Next Generation of Science Standards (NGSS) engineering performance expectations (Table 1).

Table 1. The connection between the instructional design and NGSS engineering performance expectations[4]

NGSS Engineering, Technology and the Application of Science
MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision. This particleboard project requires students to construct different concentrations of nanocellulose (CNF) and sawdust composite panels and test their strength of each.
MS-ETS1-2 Evaluate competing design solutions using a systematic process. Students are asked to compare the strength of different CNF and sawdust concentrations of panel composites.
MS-ETS1-3 Analyze data from tests to determine similarities and differences. Students will average the trials in each treatment to see if there is a significant difference between all of the treatments.
MS-ETS1-4 Develop a model to generate data for iterative testing. Students will construct and experiment with CNF and sawdust panels to model particleboard strength. Each treatment (different concentrations of CNF to sawdust) will have three trials. The class will pool and compare their data to see which concentration is the strongest.

Purpose of Study

Following Gagné's (2004) Differentiated Model of Giftedness and Talent (DMGT), this engineering investigation is designed to utilize gifted middle school students' natural cognitive abilities (intellectual, creative, social, and perceptual) to better develop their academic, technical, and engineering competencies. This investigation engages and strengthens students' logical, mathematical, critical thinking and organization abilities while simultaneously tapping into students' innovativeness and assisting in the development of usable knowledge. This is not a static inquiry but instead grows and evolves as more data is collected and shared. This type of dynamic challenge incorporates many STEM principles and promotes collaboration, transparency, and environmental ideals as students propose possible sustainable composite solutions. This engineering investigation is a vehicle for middle school gifted students to cultivate their talents.

Method

In this study, the **case study** method was used. The project work conducted with middle school gifted students was handled as a case study, focusing on the process and outcomes. Throughout the project, students developed solutions for real-world problems, and the set objectives were achieved. The study aims to document the students' participation in the project and the resulting outcomes (Yin, 2014).

Results

In this section, the processes related to the project will be presented in detail. This detailed presentation outlines the framework of the model for the instructional application.

Implementation of Project Process

In this investigation students are asked to manufacture strong particleboard panels using sawdust and cellulose nanofibrils (CNF), the latter of which acts as a natural adhesive. CNF is derived from trees and is generated by subjecting wood pulp to high shear, thereby breaking down the cellulose fibers into fibrils with nanoscale dimensions (between 1-100 nm in diameter). CNF also has a high aspect ratio (the length of the fibrils are much larger than the width). Due to its nanoscale dimensions, CNF has unique physical properties. For example, nanocellulose-based materials have high strength and low weight, and a great capacity for hydrogen bonding (Liang et al., 2022). As such CNF has great potential as a unique, renewable, and biodegradable advanced material.

Students will be able to determine if an aqueous slurry of CNF is suitable as a non-toxic, environmentally benign adhesive for the construction of particleboard. Sawdust and a 3wt% aqueous slurry of CNF (3% dry CNF by weight to 97% water) make-up the particleboard panels in this investigation. The wet composite material is placed in a mold and then the water is squeezed out to form a dewatered panel. Each panel is then dried before testing. The panel can be air-dried, placed in a food dehydrator, or oven dried at about 95°C. It is proposed that upon drying, the hydrogen bonding between the CNF and the larger wood particles of sawdust will produce solidified particleboard without the use of

[4] The NGSS (Next Generation of Science Standards) engineering standards, science and engineering practices, the disciplinary core ideas, and crosscutting concepts the particleboard research covers for grade 6-8 and an explanation of how students can meet the standards during this investigation.

synthetic polymers derived from petroleum resources (Gardner & Tajvidi, 2016). In practice, students will test different ratios of CNF to sawdust to determine which ratio creates the strongest particleboard panel.

The materials needed for the research activity are bowls (1 per group), digital scales (1 per group), rulers (1 per group), an A-frame hydraulic bench press (1 per class), baking sheets (9"x 12") (1 per group), rubber spatulas (1 per group), panel molds which include wooden and a metal arbor plates (1 per group), graduated cylinders (1 per group), 3wt% CNF (University of Maine Process Development Center ~$75/2 gal), sawdust, masses/sand, 1 gallon buckets (1 per group) and safety goggles (1 per student), access to Google Suite (1 per student).

Personal protective equipment is nominal, but students should wear eye protection. It is noted that the sawdust used should not be sourced from pressure treated lumber. A link to the CNF safety data sheet may be found in resources. It is noted that CNF is relatively safe.

The particleboard research outlined in the present paper entailed making composite panels with different percentages of CNF relative to sawdust, and then testing the panels' strength. Wooden molds were created to assist with forming and pressing the water out of the panels, see Figure 1. Both a wooden and a metal arbor plate were employed to help evenly distribute the applied pressure.

A person with basic woodworking skills and equipment may construct the molds. The blueprints to the molds can be found in the resource section of this paper. Use of these molds resulted in panel dimensions of 21 cm long by 6.4 cm wide and 0.5 cm thick. A relatively inexpensive 6-ton A-frame hydraulic bench press was used to apply pressure to the arbor plates and hence dewater the panels (Figure 2).

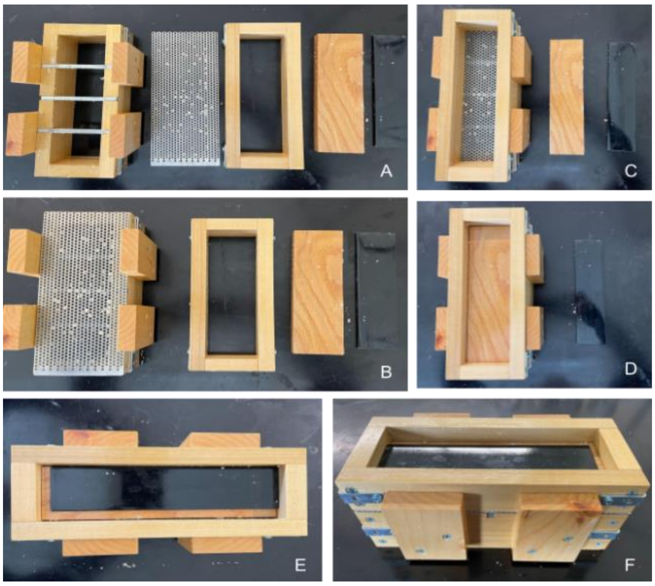

Figure 1. Particleboard Panel Mold

The molds used to make the particleboard panels were a heavy-duty wooden base with reinforcement bars, steel mesh screens, removable frame, a solid top, and both a wooden and a metal arbor plate. Detailed notes and drawings created by the Advanced Manufacturing Center at the University of Maine can be found at the following link (URL 1).

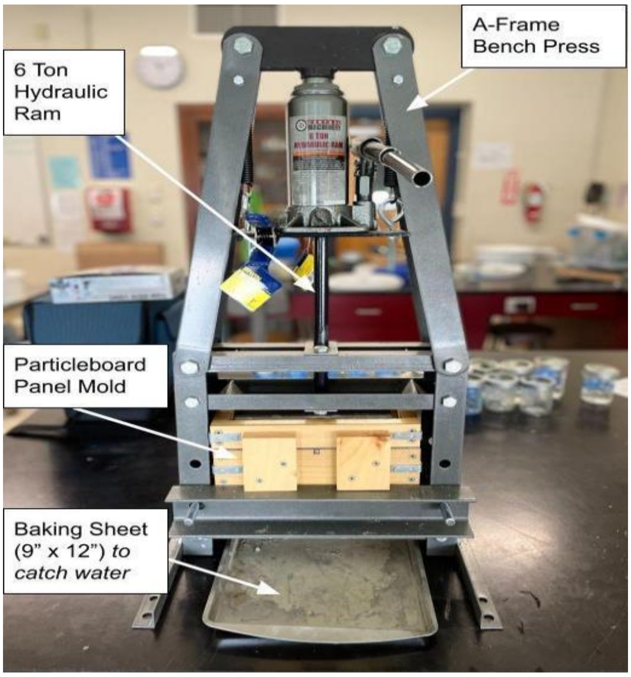

Figure 2. The 6-ton a-frame bench shop press from central machinery (model number 63995).

Once each panel is pressed and dried, the strength is determined by applying a force to the center via a bucket containing masses (for more precision, sand can be used), which is progressively increased until panel failure.

To help students calculate the relative amounts of sawdust and 3wt.% CNF slurry to mix for a given panel, instructions for a spreadsheet calculator (Appendix 1) are provided which enables production of panels of consistent dry mass (33.6 g). The spreadsheet ensures that each panel contains a precise and known ratio of dry CNF to sawdust. See Table 2 for an example.

Table 2 presents a sample calculation from the spreadsheet calculator for the production of 14 wt% CNF to sawdust ratio panel. It is assumed that the mold employed is dimensionally the same as those employed in the present work and has a volume of 67.20 cm^3 (21 cm x 6.4 cm x 0.5 cm). Column (A) is the approximate mass of a dried panel (g). Column (B) enables entery of the desired percentage of CNF per panel. Column (C) is the calculated amount of dry CNF in each panel, which is calculated by multiplying the approximate mass of panel (g) by the percentage of overall CNF per panel (14% in this example). Column (D) is the weight percent solids of the standard starting CNF slurry (3% is typical). Column (E) is the mass of sawdust to be added for each panel and is calculated by subtracting the target mass from the total dry CNF in the panel (column C). Column (F) is the amount of 3 wt.% CNF slurry to be used by mass, which is calculated as the quotient of total dry CNF (column C) and the weight percent of the CNF slurry employed (14%). Finally, Column (G) is the total mass of material needed to make the panel.

Table 2. Calculating the amounts of wet CNF and dry sawdust to use for the determined percent of dry CNF per panel

A	B	C	D	E	F	G
Approx. mass of dried panel (g) (standard)	Enter: the % of overall CNF desired per panel	The total amount of dry CNF in panel (approx. mass (g) * CNF content (%))	Starting % of CNF (standard)	The amount of sawdust (grams)	The amount of wet CNF to add (total dry CNF / starting % of CNF)	Total mass (g) of material needed
Target mass (g)	CNF content (%) ENTER Desired % Below	Dry CNF (g) in Film	CNF (%)	Sawdust furnish (g)	Wet CNF (g)	Total mass (g)
33.6	14	4.70	3	28.90	156.80	185.70

Class Introduction

As a classroom investigation, the research will likely require a one-week time period for classes that meet each weekday for at least 40 minutes. On the first day teachers may present background information, which could include a 10-minute video by Going Green (2021) called “10-Eco-Friendly Building Materials: Sustainable Design.” The class might also watch another 8 minute TEDX Video about CNF called Nanocellulose: It’s A Wrap (2017). Teachers should sShare the focus of this investigationresearch project where students will be making composites of sawdust and CNF to build the strongest particleboard panel possible without using petroleum derived adhesive.

The teacher may Sshare or have students create a data collection spreadsheet (Table 3). The data to collect inof Table 3 aligns with the wooden molds used to make panels that are 21 cm long x 6.4 cm across x 0.5 cm thick and a volume of 67.2 cm^3. The column for density contains a formula that calculates the density once the dry panel mass has been entered. Density is a physical property that many middle school students struggle to fully understand. According to the research done by Gotzer et al., (2005) students tend to hold several misconceptions on the concept of density and find it arduous to reconcile their instinctive understanding and the formal characteristics of density. So by including density in the data table it becomes an applicable physical property that requires students to focus on the relationship between mass and volume, which the concept of density requires.

Table 3. Sample Group Spreadsheet

sample group data spreadsheet for _________% cnf to sawdust						
Panel	**Panel Volume** =(21cm L * 6.4 cm W * 0.5 cm H)	**Water released** (mL)	**Panel-Wet Mass** (g)	**Panel-Dry Mass** (g)	**Dry Density** (g/cm3)	**Max Mass held** (g)
1	67.2				0	
2	67.2				0	
3	67.2				0	

Table 3 is an example of the student spreadsheet, which each group can use when collecting data. The water released and the mass of the wet panels can be used to help evaluate the panels and justify abnormal results. The mass of the dry panels and density can be compared to the original table to make sure the panels are close to the predicted specifications. The maximum mass average is the responding variable results students will pool and graph. The formula to find the average data for column 7 row 6 is “=AVE(G3:G5)”.

Making Panels

On the second and third days of the investigation the students should make the sawdust/CNF panels. The time needed to press the panels will depend on the number of A-frame hydraulic bench presses available in the laboratory. The authors have one bench press and assuming each group has a particleboard panel mold, the pressing of 15 panels (three panels per 6 groups) requires approximately 80 minutes.

Students should add their specified amounts of 3 wt.% CNF slurry and sawdust by mass (g) (information gathered from Table 2) into a bowl and mix well. Once completely mixed the students should transfer the composite mixture to the panel mold and spread evenly. The wooden arbor plate followed by the metal arbor plate should be placed on the top of the composite mixture and compressed with the A-Frame hydraulic bench press. A small cooking sheet should be placed under the press to collect the liberated water once the panel mixture is compressed. (Table 3 and Figure 2). The compression lever of the hydraulic lift should be actuated until it no longer moves. A rubber spatula may be used to ensure as much of the water is collected onto the cooking sheet as possible. Water from the cooking sheet should be measured with a graduated cylinder and volume recorded in the appropriate section on the student spreadsheet (Table

3). When the pressing of each panel is completed, the panel should be carefully removed from the mold, and labeled with the panel number and percentage of CNF (e.g., with a permanent marker). The panel should then be carefully moved to a digital scale to measure its wet weight before being taken to a drying station. The panels should be weighed a couple times hours before testing to make sure drying is complete, as evidenced by a plateaued mass. Drying typically is completed in a 24 - 48-hour time period (depending on the temperature and humidity). If a food dehydrator or ovens are available they may be used to speed the drying process.

Testing the Panels

On the fourth day students should record the mass of each of their dried panels (Table 3) and calculate the density of each to ensure that they are between 0.2 - 0.5 g/cm3. The load bearing capabilities of each panel can subsequently be determined. The load bearing procedure requires the following equipment: 1-gallon buckets, rulers, and masses or for more precision, sand. Students should employ a similar procedure to that presented in the September 2013 Science Scope article “Innovative Composite Research Modeled in the Middle School Classroom” by Vassiliev, Bernhardt, & Neivandt (p. 42 – 52). Two desks or chairs of the same height should be set approximately 15 cm apart from each other and one of the composite panels placed across the gap with approximately 2 cm of each end of the panel resting on the desk/chair. The mass of a 1-gallon bucket should then be measured before it is hung from the center of the panel to be tested. Once it is evident that the panel is capable of bearing the weight of the bucket, students should start progressively placing additional weight within the bucket. It is important to wait at least 30 seconds and listen for cracking before each sequential addition of weight. Should cracking sounds be noted, students should wait until the panel settles before the addition of further weight. Care should be exercised at all times to avoid the bucket falling to the floor when the panel fails, indeed a student should be in place to catch the bucket should this eventuate. When the panel cracks or breaks, students should record the mass of the bucket and contents. The broken panels may be disposed of in a garbage can. Table 4 is representative data collected by Grade 8 Science Fair students from Doherty Middle School, Bangor, Maine, for panels containing 14 to 20 wt.% CNF.

Table 4. Individual panel data along with average mass held for each weight percentage CNF vs. sawdust

Representative Student Science Fair Data							
% CNF	**Panels**	**Water released (mL)**	**Panel Wet Mass (g)**	**Dry Mass (g)**	**Density (g/cm^3)**	**Max Mass Held (g)**	**AVERAGE Max (g)**
14%	**Panel 1A**	52	103	31.8	0.318	389	
	Panel 2A	70	104.3	32.6	0.326	395.77	
	Panel 3A	69	108	32.87	0.3287	389	
	Panel 4A	65	113	33.35	0.3335	389	390.69
16%	**Panel 1B**	78	115	34.67	0.3467	1054	
	Panel 2B	69	129	34.69	0.3469	1573	
	Panel 3B	90	110	34.76	0.3476	1053	
	Panel 4B	91	97	34.83	0.3483	389	1017.25
18%	**Panel 1C**	97	107.26	36.5	0.365	1774.7	
	Panel 2C	94	117	34.5	0.345	1079	
	Panel 3C	100	116	34.55	0.3455	649	
	Panel 4C	97	109.6	37.1	0.371	1949	1362.92
20%	**Panel 1D**	109	119	34.4	0.344	3048	
	Panel 2D	106	115	34.67	0.3467	2249	
	Panel 3D	128	112.2	37.57	0.3757	3056	
	Panel 4D	108	124	25.23	0.2523	3554.13	2976.78

Pooling Class Data

On the fifth day, the instructor should create and share a pooled classroom data spreadsheet in Google Drive, which is accessible to all students in the class (See Table 5). The average maximum mass held by each group's panel should be entered into the spreadsheet, thereby collecting data for the mass held at each sawdust/CNF ratio. The class may then create a bar graph of all the treatments (weight percentage of CNF to sawdust as the manipulated variable and the average maximum mass held (g) as the responding variable). Figure 3 is a representative graph created by 8th grade science fair and engineering fair participants. Standard error lines may be added to the bar chart if desired (described in Figure 3).

Table 5. Pooled Classroom Data

Template for Pooled Particleboard Classroom Results	
% CNF	Average Max Mass Held (g)
14%	
15%	
16%	
17%	
18%	
19%	

Spreadsheet of pooled average maximum mass held each group's three panels. These data may then be graphed as a bar chart with standard error bars, see Figure 3. To include the standard errors on the bar chart your click on edit chart, select customize, go to series and select standard errors.

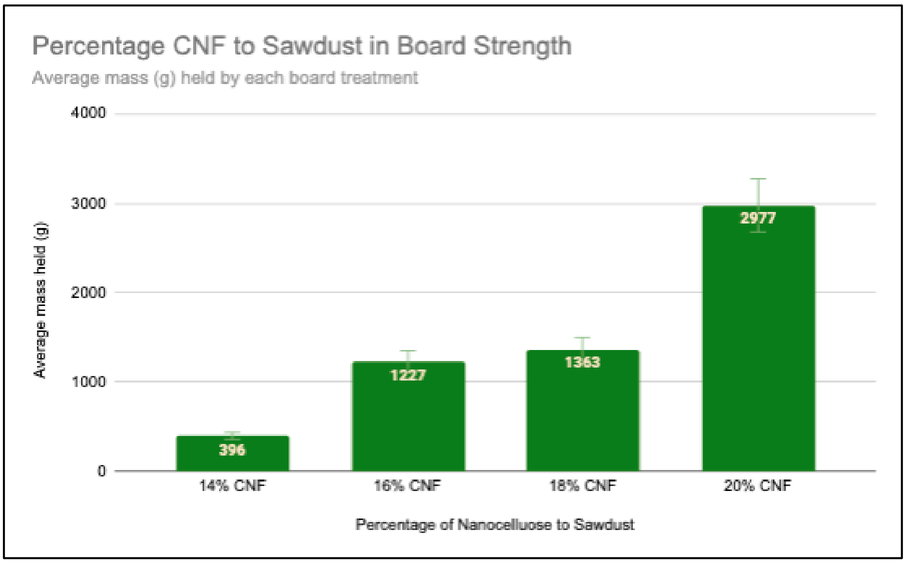

Figure 3. Representation of percentage CNF to sawdust in board strength

Investigation of Figure 3 revels that the panel comprising 20wt% CNF held the most mass.

Communicating Results

At this point in the investigation students may be asked to collaborate within their groups to generate a digital (Google Slides or Canva) or physical (poster paper or trifold) quad chart (Table 6) outlining and communicating their findings. A quad chart is a simplified poster presentation that divides the investigation into four concise sections (Vassiliev et al., 2024). The first section is where students introduce and summarize their rational for using certain ratios of CNF to sawdust. The next section is for the procedure. Then the results are displayed and finally the last section is for each group to reflect upon the experiment and articulate any weaknesses or suggest means to improve and extend the research process. Each student group will copy the graphed results into their own quad chart but approach the procedure and conclusion from the perspective of their chosen panel ratio (CNF/sawdust). A Google Slide (Google Suites) version of the Quad Chart Template and Scoring Guide can be found in Appendix 2. Each research group will present their own quad chart from their research perspective.

It is noted that the use of a shared data allows instructors to perform timely formative assessment feedback of group work and progress and encourages classroom discussion. Instead of having students write full laboratory reports, the quad charts are more condensed summative assessment, which simulates one-approach scientists and engineers use to report and share their own research findings. Once the investigation is completed it opens the door for students to take this research further as a science and engineering fair project. More ratios can be tested and/or alternate inorganic or organic materials added to the composite to try and make the panels even stronger.

Table 6. Outline and scoring guide for a group particleboard quad chart

THIS IS WHERE YOUR TITLE GOES *(Title needs to be detailed and give the reader a good idea of what the research is about)* Student Names	
Research Questions	**Data Analysis And Results**
• Put your research question here. • Please do not write in 1st person. Try just stating what you want to say without “I think” or “my research.” • Provide background information. What does the audience need to know about your research topic? • Hypothesis: what do you think will happen and why? • Pictures of your experimental design or other important aspects of your research. ** 25 points section contains all of the above, 24 - 20 missing one to two aspects, 19 - 15 missing 3 aspects, 14 - 0 missing 4 aspects or all.*	• Data analysis and group results should go here, including graphs and other visual data. • You should have a brief description under each graph (use a smaller font) that describes the graph, diagram, image, etc.... • Highlight JUST THE FACTS. • Make sure each graph, diagram, etc. has a title and all the necessary labels. • Use standard error bars when appropriate or linear regressions for correlations. **25 points section contains all of the above, 24 - 20 missing one to two aspects, 19 - 15 missing 3 aspects, 14 - 0 missing 4 aspects or all.*
Methodology	**Interpretation and Conclusion**
• Your methodology should go here. Consider using something like a flow chart or numbered list to help break up the words into manageable chunks. • Provide enough details so that the reader could repeat your experiment and expect to get the same results. You do not have to include incidental information (ex. where you purchased your materials), but you must include the fundamental aspects of your research (ex. Explain what each treatment is and how many trials you did). • You can discuss the statistical approach, but do not state the obvious like you collected the data in a spreadsheet. **25 points section contains all of the above, 24 - 20 missing one to two aspects, 19 - 15 missing 3 aspects, 14 - 0 missing 4 aspects or all.*	• This is where your conclusions should go. • Now discuss your results. You may include inferences here if they are supported by your data. • Address your original hypothesis. If the hypothesis was not supported address it. If you believe there was a flaw in your experimental design, discuss it here. • What is the next step to your research? What would you like to investigate next to expand on this research question? ** 25 points section contains all of the above, 24 - 20 missing one to two aspects, 19 - 15 missing 3 aspects, 14 - 0 missing 4 aspects or al*

Concluison

The student outcomes for this activity not only meet the performance expectations outlined in Table 1, but also many of the Next Generation of Science Standards (NGSS) enginerring performace expectations. In addition, students will complete aspects of all of the science and engineering practices, explore several engineering disciplinary core ideas, and consider several crosscutting concepts. Introducing students to the importance and necessity for sustainable and safe building materials is the means to tap into their empathy and social righteousness. This challenge is truly rooted in real world cutting edge problem solving that makes these student outcomes applicable and powerful.

Science and Engineering Practices

Science and engineering practices are the tasks, skills, and explicit knowledge students employ to make sense of the world around them. These science and engineering practices guide students to start internalizing and transferring their explicit knowledge to tacit knowledge and therefore wisdom. Evidence of where each practice is undertaken in the present investigation can be seen in Table 7. The first practice is about having students “**ask questions and define problems.”** Not only do students asked questions about how they can develop a strong and environmentally stable particleboard panel, but they are also asked to pontificate about future research that could be pursued to piece together another part of this material science investigation.

For "**developing and using models"** students model the material science research being done at the University of Maine. Manufacturing and then testing CNF and sawdust composite panels produce scientifically sound results while also being relatively straightforward to implement in a gifted middle school laboratory. The class has the flexibility to "**plan & carry out an investigation"** the way they feel works best to answer the questions they put forth. These questions can focus solely on ratios of sawdust to CNF or students can choose to expand on the components of the composite to determine what makes the strongest panels in their study.

Quantitative literacy is established with students collecting, and "**analyzing and interpreting data."** Students will collect and manipulate spreadsheet data to determine derived units such as density and averages. Students will create and interpret graphs. Since the class is pooling their data each group will come to understand that they must help in maintaining the integrity of the class data. A representative graph can been seen in Figure 3 where panels made with 20% of dry CNF were shown to be significantly stronger than any other ratio of CNF panels to sawdust. "**Mathematics and computational thinking"** is also required of the students as they not only use Google spreadsheets to collect, pool, and graph their data but they are also required to interpret their results to "**construct explanations."** The ability to make such connections and employ abstract thinking is relatively standard for gifted students.

Middle school is when students start really building their executive functioning skills. The present investigation requires students' focus, planning/prioritization, and organizing of data in spreadsheets. Observations must be meticulously recorded and simple statistical formulas inserted into spreadsheets as well. Testing panels requires patience, accuracy, and precision. Students collaborate to explain their results by "**engaging in argument from evidence"** by presenting their work in quad charts (Table 6), which is how, students "**obtain, evaluate, & communicate information."** Quad charts are a quick means for students to articulate the purpose, process, and main findings of their research. Gifted students are able to be metacognitive of how their group results fit (supports or not supports) the overall class results. The quad charts model is one-way scientist and engineers share their results and engage in conversations that help make sure the science and engineering results and analysis are sound.

Disciplinary Core Ideas

The NGSS engineering disciplinary core ideas that are met with this investigation are the "designing and delimiting engineering problems," the "developing possible solutions" and "optimizing the design solutions." This engineering challenge brings students full circle with them initially designing a project on which they want to focus and then defining the parameters of the experiment to test the strength of alternative particleboard panels. The equipment used during the entire process is unique and more sophisticated than what students typically use in a middle school science laboratory. Using these manipulatives to dewater and dry each panel before testing helps students to better conceptualize a solution by making them consider possible physical and chemical interactions going on at the microscopic level. Each group tests and averages the results for their panels and then the investigative results are optimized when students pool their group's data with the entire class to determine which CNF and sawdust panel composite performed the best in holding the most weight.

Crosscutting Concepts

Students will enforce their quantitative literacy skills as they collect, manipulate, and analyze patterns in their data. Students witness the effect of adding different amounts of CNF to sawdust in panels which in turn causes the panels to increase or decrease in strength. Based on the evidence that is collected, students are able to make predictions about the strength of the panels based on the different ratios of sawdust to CNF. In addition, students gain first-hand experience in how science, engineering, and technology directly influence the innovation of developing stronger particleboards without using synthetic binders and resins.

Table 7. The connection between the instructional design and NGSS science and engineering practices, disciplinary core ideas, and crosscutting concepts

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking questions and defining problems. Students determine the best ratio of sawdust to CNF that constructs the strongest panel. **Developing using models.** This entire research project is a model in investigating alternative particleboard strength. **Plan & carry out an investigation.** Students will select the different concentrations of CNF to make that strongest panels **Analyzing and interpreting data.** Students will collect data. They will then average the max mass that broke each panel of all the different treatments to discover which composite could hold the most weight. **Use mathematics and computational thinking.** Students will use Google spreadsheets to collect, pool, and graph their results. **Construct explanations.** Students will be able to explain their results and come to a conclusion as well as explain any data anomalies. **Engaging in argument from evidence.** Once students pool and graph their data they will use the evidence to determine what concentration of CNF and sawdust makes the strongest panels **Obtain, evaluate, & communicate information.** Students will communicate their results to the class and make recommendations for the next steps.	**ETS1.A Designing and Delimiting Engineering problems.** This project asks students to test the strength of an alternative particleboard. To find one that is more environmentally friendly. **ETS1.B: Developing Possible Solutions.** Students will use their critical thinking skills to test a possible CNF to sawdust ratio pane that could be used as an alternative to traditional particleboard. **ETS1.C: Optimizing the design solutions.** Students will compare the results from their entire class to a control to see which CNF and sawdust panel composite performs the best in holding the most weight.	**Patterns.** Students will use their research to identify patterns in their data **Cause and effect.** Students will be able to make predictions about the strength of the panel based in the ratio of sawdust to CNF. In addition, students will experience the influence of science, engineering, and technology have in the innovation of developing stronger particleboards without using synthetic resins. **Structure and Function.** Students will discover how the composition of sawdust and CNF can affect the strength of the panel.

Disucssion

This gifted middle school material science investigation, in which students evaluate the potential of an environmentally benign binder (CNF) to replace petreoleum-derived resins in the production of particleboard panels, provides real world experiences, relevant solutions, and useable knowledge. This investigation into sustainability combines two innovative pedagogical strategies, the engineering design process and challenge-based learning. The goal is to *"foster student ownership of real-world problems (Meyer et al., 2020, p. 5)"* and get students to implement science and engineering practices in a meaningful way. When students are tasked with finding safer, more energy efficient, and environmentally friendly building materials then the research takes on greater importance. According to Tomlinson (2009) "*A theory of knowledge that has, as its goal, helping learners experience and appreciate real-world applications for the knowledge they learn in school should also emphasize the appropriate use of methods, tools, and techniques used by experts in and contributors to a field (p. 9).*"

The open-ended particleboard investigation discussed in this paper accomplishes this along with highlighting several sciences and engineering practices that challenges advanced middle school learners. In the authors' experience, students increasingly care about sustainability and safety; we as teachers can assist them by highlighting actionable research, which can be brought to bear. Students can be shown that engineering, math and science are meaningful tools, which can be used and honed to make impactful changes in the world and our communities. Professional development opportunities like the Hub & Spoke SM^{2}ART project's RET program with the support of the U.S. Department of Energy (DOE) are also a crucial parts of this equation. It was this program's expertise that allowed for the collaboration, development, and classroom optimization of this curriculum module and is the inspiration behind the present activity.

Overall, this sustainable and eco friendly materials science investigation mirrors the current engineering explorations being done at a plethora of research facilities like the University of Maine. In this article, students are asked to investigate a sustainable and non-toxic particleboard composite that is more environmentally friendly. The research is challenging, relative, and requires science and engineering practices. Students are asked to work in small groups to make and test their particleboard panels to determine the average maximum weight each panel can hold. They are asked to be metacognitive of their methodology and use extenuating data to justify the integrity of their results before pooling their data with the class. Having students use spreadsheets with formulas requires strong procedural knowledge, which reinforces their critical thinking and problem solving skills. The group quad chart summative assessment allows students to assess their own work and how it fits in with the class results. The ability to critically examine, understand, and communicate how their group results melds, supports, or does not support the overall results, is evidence, in itself, of high-level learning.

"Design challenge units are an effective way for teachers to guide students in the construction of useable knowledge within and across content domains, as they work on complex problems" (Meyer et al., 2020 p.21). Engineering design challenges connect students' previous content knowledge and new information in meaningful ways with real world applications. Teachers of gifted and talented students can easily tap into students' elevated sense of empathy and justice to create a solid, humanitarian hook. Gifted students are better able to understand more abstract concepts and more readily make connections between their middle school science content knowledge and the new information they take in during an engineering challenge. Inquiry investigations like the one described in this article open the door for students to tailor and level up the research for a science and engineering fair project that requires an even deeper dive into the topic. All of nuances found within this activity can be overwhelming for grade level students, but for gifted learners they often excel and better appreciate the experiences they get with science and engineering practices. It is the author's experience that gifted students become more intellectually curious about the world around them and their possible impact for improvement when they are exposed to design challenges like the one described above.

Recommendations

This material science investigation was developed to provide a meaningful and challenging activity for middle school gifted students. It is a robust activity that encapsulates and distills the cutting edge research being done at the University of Maine and is being successfully used as a vehicle to get gifted middle school students invested in a real world problem solving activity. The engineering design challenge engages and reinforces executive functions, metacognition, and helps to foster the talents of gifted students.

The particleboard challenge can easily be modified for gifted student pullout programs or gifted classes. As a physical science teacher, the lead author conducts this particular engineering challenge early in the school year after reviewing physical properties of matter. While grade level classes are exploring particular physical properties of objects like density and viscosity, she is able to easily intergrade all the same content and more within the engineering challenge for the gifted students. This particular engineering design project evolves each year. If teachers are able to keep the posters from year to year it adds another layer to the project by pushing students to expand on the research from previous years.

More academic research is recommended to scientifically evaluate the effectiveness of such instructional design on students. This could be done with pre and post quantitative surveys to probe attitudes toward science and engineering practices, content knowledge, and the impact of engineering challenges on authentic and independent research projects.

Limitation od Study

This research is limited primarily to curricula activities implemented in 8th Grade at the James F. Doughty School, in Bangor, ME, USA physical science class in the period 2021-2024. A total of approximately 80 students have undertaken the activity, instructed by lead author Vassiliev. In addition, the activity served as the basis for a statewide middles school science competition in which two 8th grade students won the Lemelson Award. The activity has been disseminated to both the grade 6 middle schools in the Bangor School District via a teacher-in-service workshop and it is anticipated that it will be implemented in several grade 6 earth science classes during the current academic year.

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URL

URL 1. https://drive.google.com/file/d/1RctCdkofATW_NEz6V3gbLgh2I9FDJHXh/view

Technical drawings for making the particleboard panels

URL 2.

https://secure.touchnet.com/C22921_ustores/web/store_cat.jsp?STOREID=216&CATID=392&SINGLESTORE=true

Purchase CNF

URL 3. https://umaine.edu/pdc/wp-content/uploads/sites/398/2022/07/SDS-CNF-v2.pdf

Safety data sheet fro CNF

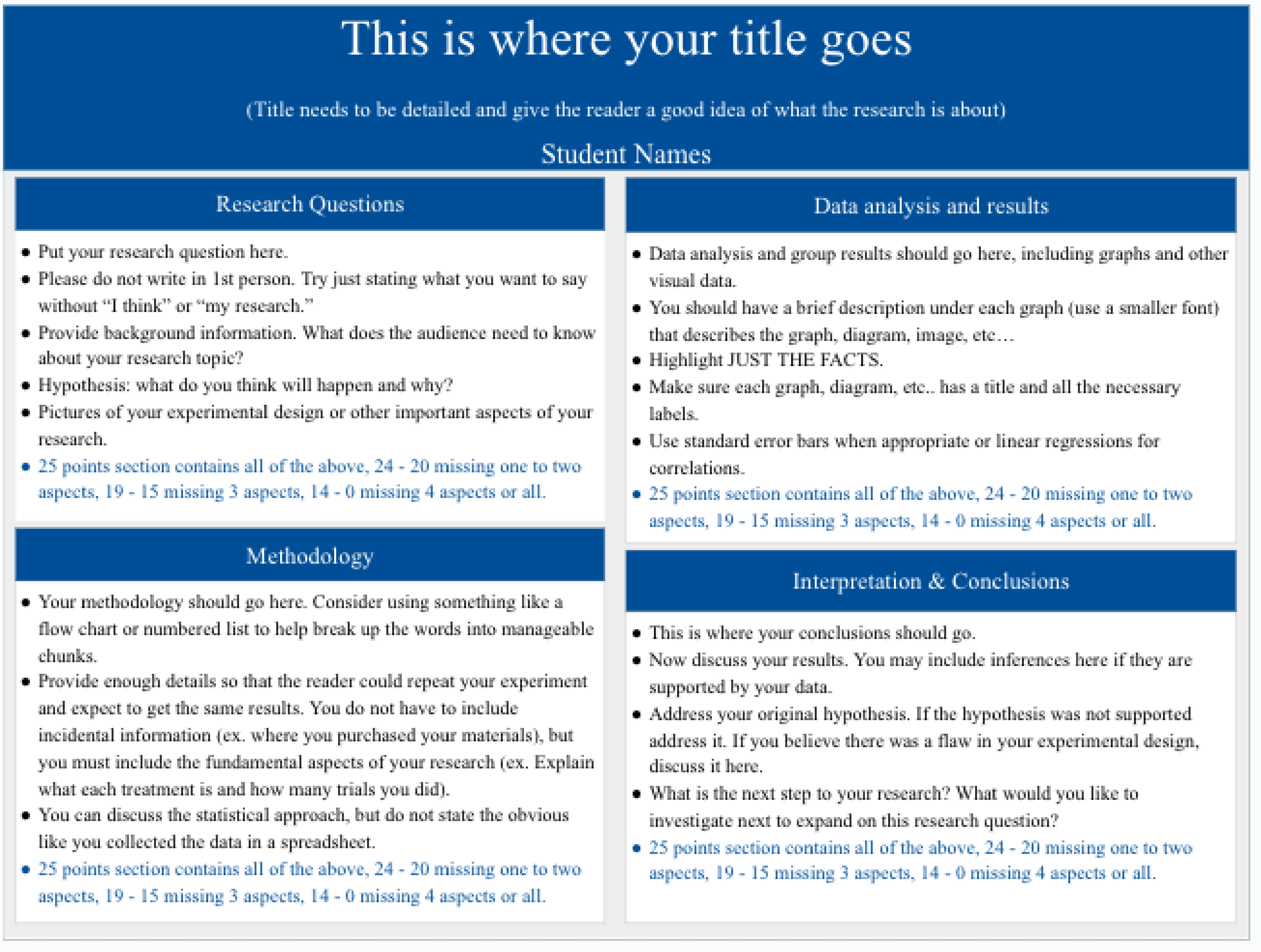
Appendix 1. Spreadsheet instructions for calculating the amount of wet CNF and sawdust to us for a desired percent of CNF per panel

A	B	C	D	E	F	G
Approx. Mass of Dried panel (g) (Standard)	Enter the % of overall CNF desired per panel	The total amount of dry CNF in panel (approx. mass (g) * CNF content (%))	Starting % of CNF (Standard)	The amount of sawdust (grams)	The amount of wet CNF to add (Total dry CNF / Starting % of CNF)	Total mass (g) of material needed
Target mass (g)	CNF content (%) ENTER Desired % Below	Dry CNF (g) in Film	CNF (%)	Sawdust Furnish (g)	Wet CNF (g)	Total Mass (g)
33.6	14	4.70	3	28.90	156.80	185.70

- Column (A) is the approximate mass of a dried panel (g). The standard mass for a panel with the following dimensions: 21 cm x 6.4 cm x 0.5 cm.
- Column (B) is where you enter the desired percentage of CNF per panel.
- Column (C) is the calculated amount of dry CNF in each panel, which is calculated by multiplying the approximate mass of panel (g) by the percentage of overall CNF per panel (14%). The cell formula is "=A3*B3/100"
- Column (D) is the standard starting CNF slurry (3% is typical).
- Column (E) is the mass of sawdust to be added for each panel and is calculated by subtracting the target mass from the total dry CNF in the panel (column C). The cell formula is "=A3-C3"
- Column (F) is the amount of 3 wt.% CNF slurry to use by mass that is calculated as the quotient of total dry CNF (column C) and the weight percent of the CNF slurry employed (14%). The cell formula is "C3/(D3/100)"
- Column (G) is the total mass of material needed to make the panel. The cell formula is "=Sum(E3:F3)"

Appendix 2. Quad Chart Template and Scoring Guide

A quad chart template and scoring guide made with Google Slide (Google Suites). Each research group will present their own quad chart from their research perspective.



https://docs.google.com/presentation/d/1DATLRw4mPWjvxZqei_Kd5gohck9Oryir3Nx9yLcHn0Y/edit?usp=sharing