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Developing a Learning Innovation for an Undergraduate Mechanical Engineering Course through Faculty, Engineer, and Student Collaboration

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Abstract

Engineering education research is often motivated by closing the gap in students' preparedness for the engineering industry. One way to achieve this is by developing authentic learning contexts, activities, and problems that are representative of the engineering workplace. This approach is not novel in engineering education research or the engineering curriculum; however, only a limited number of studies have closely and collaboratively worked with students, faculty, and engineers to develop learning innovations (LI). This study aims to further address the gap in preparedness by developing innovations that are representative of the engineering workplace, aligned with course learning outcomes, and informed by the experiences of students. Additionally, this study also aims to research participant beliefs related to the development of these innovations to help understand more about what it means to be an engineer and potential barriers to adoption. This publication is a work in progress as only partial results of one developed innovation draft will be shared. Future results will include additional innovations and analysis of the collaboration between students, engineers, and faculty members.

At the beginning of the fall semester of 2023, participants engaged in a collaborative workshop to develop a LI for an undergraduate Mass and Heat Transfer course. The innovation was developed with a faculty member teaching the course, a student participating in the course, and an engineer who works closely with the concepts taught in the course. Including these three participants represents the involvement of the three major stakeholders related to the use of this LI. The results from the workshop informed the development of the LI and aligned the innovation with what is feasible for the course. It also ensured the innovation was representative of practical engineering problems and maintained a complexity consistent with the students' understanding when entering the course. The innovation is currently in the process of development and will require students to work on solving a complex open-ended problem over a period of 3-5 weeks. The innovation was nearly adopted in the fall semester following the workshop, but course logistics and other constraints prevented adoption. The practicing engineer will continue to collaboratively develop the innovation with the faculty member and student. Each research participant was interviewed following the initial development of the LI with the goal of learning more about their opinions and beliefs related to the collaborative development of the LI and its eventual use in the classroom.

The results of this publication include a draft of the LI and a discussion of the findings related to the collaborative development of the activity, as well as perceived barriers to adoption.

Introduction

Engineering programs are designed to prepare students with the knowledge and skills needed to become successful engineers. There are inherent differences between the academic and workplace contexts that are widely discussed in literature [1], [2], [3]. The application of content in the academic context is quite different from the real world. Academic problems tend to have a clear, step-by-step solution that often leads to a single answer. Conversely, engineering problems tend to be ill-structured and ambiguous without a single clear answer [4]. Some of the reasons for these differences relate to the scaffolding required to introduce students to concepts and to assist with the evaluation of learning outcomes. This gap is not novel to engineering education research and is often overcome with on-the-job training that help prepare recent graduates for their transition into the workplace. While most would agree that complete preparation for all engineering careers is not the intent of a student's engineering education, it would be fair to say that addressing this gap holds value for the major stakeholders. We define the major stakeholders as the student, faculty, and engineering practitioners (or firm/agencies) that will employ the student.

Students value opportunities to "practice the engineering profession" and have exposure to engineering processes through authentic projects [5]. In a recent study, students completed an engineering course on changeable and reconfigurable manufacturing in a classroom factory environment. The purpose of the study was to apply blended and project-based learning to teach students about the requirements and realities of the modern manufacturing environment. After working in a classroom factory environment, students stated that their workplace-like environment helped to transfer their theoretical knowledge into practical experience. This learning environment also increased student engagement [6]. In a different study, industrial partners developed authentic engineering problems for students to solve. The partners presented the problems in the classroom, listened to students' solutions, and then offered feedback. The study found that having industrial partners present motivated students to invest time into solving difficult authentic engineering problems [7].

Project-Based Learning (PBL) is a well-researched approach that may allow students to experience the types of problems they will experience in the workplace [8]. Engineering problems in the workplace are often different from those given to students in traditional academic contexts [4]. Many educators utilizing PBL have tried to offer projects and problems that follow a more realistic, ill-structured format. Through engaging with these projects, students benefit from practical experience and develop useful skills associated with communication and project management as well as a better understanding of the sort of tasks they may be doing once employed [9].

Students are also exposed to the engineering profession and practical problems in capstone courses offered in most engineering programs. This exposure is not novel to engineering education curriculum and provides a level of breadth and exposure not common to other discipline specific engineering courses. Capstone courses typically span multiple terms or an entire academic year and include industry mentorship and guidance while developing solutions for a complex open-ended design [10], [11], [12]. The intent of these courses is different from other discipline specific courses in that they provide a culminating experience meant to be the "capstone" of a student's engineering degree. They foster professional development and real-world problem solving. The aims of these courses and other project-based learning methods are similar to the aims of this research; however, the intent of this research is not to recreate or mimic a capstone design experience. Instead, the intent of this research is to provide more opportunities for students to engage with practical design problems earlier in their degree and to create LIs for courses that align with the needs and opinions of the three major stakeholders in the academic process while addressing any barriers to adoption.

One common barrier to adoption of new teaching strategies is that a change in teaching methodology often requires time, effort, and resources from educators [13]. Andersen et al. (2019) developed a factory classroom environment to provide students with a unique, immersive learning experience. While the class was positively perceived, it required substantial resources and coordination to develop and maintain. Similarly, it has been found that Project Based Learning (PBL) has increased the workload of teachers and increased the demands for more supportive materials and resources for teachers [8]. There have been calls for more facilities and spaces to compliment PBL as well as for trainings to teach teachers how to successfully facilitate PBL [4], [8]. Another source of difficulty for educators is the time consumption of new methods, such as inverting their classroom and finding industrial partners to help create authentic engineering problems [14]. Additionally, teachers have been struggling with pressure to cover the same amount of content while using new teaching methods [4]. These challenges may discourage educators from adopting, and developing, new LIs.

While new teaching strategies and innovations may be beneficial to students, there is a tendency for students to resist change in classrooms. The implementation of "deep learning experiences" may result in student resistance and dissatisfaction [4]. It has been observed that students tend to resist change when it alters the way they learn and process course material or seems like more effort [14]. The resistance of students to change creates a barrier to adoption for new teaching practices and innovations [13]. However, a number of strategies have been used to mitigate student resistance [15]. Some of these strategies include walking around the room and approaching non-participants, inviting questions, and explaining course expectations. The previously mentioned strategies, among others, have resulted in greater participation from students, students being less distracted, and positive course evaluations [15]. The use of strategies to mitigate student resistance may be useful as educators develop LIs to engage students and lessen the gap between the academic and workplace context.

To understand more about the gap between academic and the real-world problems, cross-discipline engineering education collaborations have been practiced. Engineering education is a relatively new discipline that seems to share more attributes with social sciences than with traditional engineering. Because of this, it is likely that engineering education would benefit from interdisciplinary approaches to collaboration although engineers are unlikely to participate in this approach as it makes them uncomfortable [16]. A common critique of engineers is that they are "particularly unlikely to consider other perspectives" which is a requirement for interdisciplinary work [16]. Engineering students need to have the ability to see, evaluate, and select from different perspectives that have influence on a problem [16] and there is hope that learning innovations developed from interdisciplinary collaboration may help students develop these abilities. Perhaps collaboration between students, faculty, and engineers could decrease student resistance and increase interest by creating connections to the real world. This inspires the research question: what can be learned from the collaboration between engineering students, faculty, and practicing engineers while developing authentic engineering problems for use in the academic context?

This publication is a work-in-progress for a larger study that will detail the LI, results from in-class adoption, and the participants' opinions and beliefs related to the collaborative development of the LI. Preliminary results and discussion in this publication focus on the opinions of participants from the collaborative workshop. The current innovation is being iterated between participants and only preliminary details are presented.

Methods

To address the research question, we conducted a collaborative workshop with an engineering practitioner, engineering faculty member, and an undergraduate student to develop a LI for an undergraduate Heat and Mass Transfer course. Following the workshop and preliminary development of the LI, semi-structured interviews were conducted with each participant to learn more about their experience developing the LI. Excerpts from these interviews and the workshop are used to describe the preliminary results of this project. Institutional research board approval was obtained prior to all data collection.

Participants

We recruited an engineering faculty member based on their interest in participating in this study who teaches undergraduate mechanical engineering courses at the same institution of the PI. Convenience sampling was used to recruit the engineering practitioner with design experience related to heat and mass transfer, and an undergraduate student enrolled to take the heat and mass transfer course[17]. This course was chosen based on the interest of the faculty participant to develop a new LI.

Pseudonyms are used for each participant in this study. The engineering faculty member, Sullivan, is a professor at a medium sized university in the Pacific Northwest and has over 9 years of teaching experience in mechanical engineering having taught the heat and mass transfer course several times. The engineering practitioner, Templeton, has a doctorate in mechanical engineering and has been practicing mechanical engineering for over 16 years. Templeton has some problem development experience from teaching during doctorate studies and has collaborated with other faculty on senior design projects as an engineering practitioner. The undergraduate student, Remy, is a fourth-year senior engineering student at the same university as the engineering faculty member. The faculty member had taught the student in a pervious course and had also worked with the engineering practitioner early in their career.

Workshop and Interviews

A two-hour collaborative workshop facilitated by the PI was held in the summer of 2023. The intent of the workshop was to determine a topic for the LI and to begin development of the innovation. The PI facilitated conversations between the participants with the intent of learning more about decisions during the planning and development of the LI. The PI also made sure each participant was able to, and felt comfortable, offering their ideas and criticisms throughout the process. In this way, no one participant could control the development process or find their opinions unwelcomed. The PI also aimed to interfere as little as possible during the workshop and development process to limit their bias and influence on the development of the LI. An outline of the workshop is shown in Table 1 with a brief summary of the workshop in the following paragraphs.

Table 1: Outline of the Collaborative Workshop

Objective	Estimated Time
PI and Research Study Introduction	5 minutes
Participant Introductions	5 minutes
Scoping Contexts for Learning Innovation	30 minutes
Learning Innovation Development	70 minutes
Wrap Up and Future Work	10 minutes

The workshop was facilitated in a semi-structured format to allow flexibility in the development of the learning innovation. After a brief introduction from the PI about the intent of the workshop and this research, each participant introduced themselves and provided information about their engineering design experience and education. During the recruitment phase, the Templeton drafted three potential contexts for different learning innovations. Templeton had done so unsolicited, but this proved to be an efficient approach because the scoping phase was likely more efficient with these contexts prepared ahead of time. Following participant introductions, these contexts were presented and discussed with the intent of choosing one context for the course.

The discussion focused on the feasibility of the context as a learning innovation and its relevance to the concepts taught in the course. During this initial scoping phase, each participant would suggest potential benefits and disadvantages of each context. During one notable exchange between participants when discussing the feasibility of one of the contexts, Remy mentioned, "So if you pull controls into a heat transfer class, I think the students will panic pretty hard", leading Templeton to ask, "Okay. What about just the heat transfer aspects of the plate itself?" This prompted both Sullivan and Remy to agree. These exchanges occurred throughout the scoping process and led to the selection of one context for LI development. The LI is presented in Appendix A and described in the Results and Discussion section.

Following the scoping phase, the participants developed the learning innovation in a collaborative manner with each participant sharing their opinions throughout the process. Excerpts and additional details related to this portion of the workshop are described in the Results and Discussion section.

Following the development of the LI, semi-structured interviews were conducted with each participant independently to learn more about participant opinions and beliefs related to the innovation development process [18]. The workshop and interviews were audio-recorded with each participant's consent and transcribed by a third-party transcription service for analysis. Interviews were conducted using the protocol in Table 2. Additional follow-up questions were asked related to responses from the participants.

Table 2: Relevant Questions from the Semi-Structured Interview

1. What is your experience with problem development for an academic setting?
2. What are the benefits of having a faculty member a student and an engineering practitioner develop problems?
3. What are the disadvantages?
4. Is there anyone else that should be part of the development process?
5. Should more faculty, engineering, practitioners, and/or students be involved to develop one particular problem/project?
    a. Why or why not?
6. Have you worked with (PICK ONE: faculty or students, engineers or students, faculty or engineers) before in the development of engineering problems?
7. Would you do this again? Why or why not?
8. Are there changes that you would make to the development process and workshop?
9. Would you prefer that no one is involved?
10. What do you think of the current problem?
11. Are there changes that are needed to be made to this problem/project?
12. What do you suspect would be potential barriers to adoption?
13. What might prevent this sort of collaboration going forward? For others in general.
14. Is there anything else you'd like to add?

Results and Discussion

The results of this publication focus on the development process and aim to highlight participant opinions related to the development of the LI in a collaborative workshop. Excerpts from the workshop and the semi-structured interviews are used to describe relevant feedback from the participants.

The results of the workshop lead to the development of a draft multi-problem design activity (Appendix A) that asks students to develop a cooling helmet for rats to test the efficacy of hypothermic treatments for the brain immediately following a traumatic brain injury (TBI). This problem was inspired by the engineering practitioner who worked on the design of a rat cooling helmet. This design was suggested by the engineering practitioner as a "fun" and "unique" way of bringing thermodynamic concepts into a course in an unconventional way. Templeton described their inspiration to suggest an unconventional problem like a rat brain cooling helmet as, "we need to stop thinking about how did the guy a hundred years ago figure out how to solve the problem that's in the book, that's a straight plain tube". Both the faculty member and student were immediately intrigued by the intent of the design and agreed that an unconventional design could lead to more student engagement during the design process. Each participant emphasized the importance of engaging students through less conventional means to generate a fun atmosphere and more overall interest in an academic problem. Remy stated:

> *I feel like as a student, I would have a lot of buy-in into the rat cooling helmets because it's completely different from everything else. I don't know if that's just a me thing, but it's*

so bizarre and interesting and I think that it would show students, even if you go in a different direction and you're not working in automotive or HVAC or whatever the case may be, you still have to know heat transfer. And here's why, because you could be designing a rat cooling helmet!

Each participant was respectful of differing opinions during the workshop and welcomed criticisms from each other throughout the development process. There were multiple instances where the student offered criticism for overcomplicating the problem. One particular instance is captured when Remy pushed back on the timing of scaffolding the problem when they said, “So we [research participants] would have to make sure that students would have a good amount of time to get materials, contact technicians, build things, break it, build it again to be successful and have all the resources they need”. Here Remy suggests that they be mindful of how long students must work on deliverables. When discussing the potential for writing code in Ansys, Remy also stated, “I do not think that we [students] know how to write [the code] at this time. If [Sullivan] did that for us, we could probably do it or [Sullivan] could maybe talk to [previous professor] about how to incorporate it.” Remy is expressing apprehension of a complicated coding procedure that could be difficult for themselves and other students in the course. These instances and others not captured here, highlight a potential benefit of involving students in the active collaboration by bounding the innovation within current student understanding.

Throughout the workshop, each participant also agreed that having industry involvement with the development and adoption of a practical problem was beneficial for student engagement and practical experience. When discussing the potential to include CAD work in the project, Remy stated that, “I think it would also be good to prepare students for going out into the real world where you do have to use CAD and you do have to modify things.” Remy also stated that:

It's kind of fun, very stressful, but students really want to succeed in front of industry professionals. So, if the problem is presented by you or by another engineer, students will be like, wow, this is real. This isn't just a made-up problem. This is serious. I should put in full effort or combine that with a game and then it's a win-win win.

When describing potential benefits of a practical engineering problem, Templeton expressed concern that there is a “growing divide” between academic problems and practical problems. Templeton expressed that, “… understanding how you can both meld in the kind of high undergraduate or entry level graduate analysis of heat transfer and marry that to practical limitations in manufacturability. That's kind of the sweet spot that we [engineering firm] operate in.” Sullivan echoed this concern when they said, “I want them to know that if I turn these knobs, if I change these variables, if I stretch this out or make this bigger, this smaller or whatever, how is that playing with the fundamentals?” This suggests that exploring practical problems as LIs aligns with the needs of industry and the concerns that faculty have for student preparedness.

Each participant also agreed that an unconventional incentive could increase student engagement. A competition or other ways of celebrating innovative designs were suggested. Some examples include Templeton stating, “Whoever gives me the best, most unique or innovative geometry wins period”, and “this is the Rube Goldberg award that goes to this guy who did this thing that would technically work but kind of went around the block five times to get there, sort of a thing.” Remy agreed, “I really like that idea because to be perfectly honest, heat transfer is a bit of a soul crusher and I feel like most of us walk out of class being like, ‘Wow, that was really hard and I do not feel smart’.” Sullivan suggested, “We could get [Templeton] to hand out the award in the end, but also with the buy-in that highlights the fact that you're [Templeton is] looking for engineers and these are all seniors.” Here Sullivan is suggesting that students recognize the difference in applying themselves for academic work versus a potential job. While recruitment is not the goal of this innovation, it is a perceived benefit that each participant also shared.

When discussing the innovation and the collaborative workshop during the semi-structured interviews, each participant shared their perspective on perceived benefits, disadvantages, suggested improvements, and potential barriers to adoption.

Each participant agreed that the collaborative process was beneficial. Sullivan described it as, “it's like having the buyer and seller kind of work together.” Remy echoed this in their interview when they said:

> *And so, by having an engineer sit in, you're provided with the real-world connection that students are seeking. By having a professor, you can make sure that it stays relevant to what's going on in the class and doesn't really go beyond what students are trying to learn. And then when you have a student involved, I think it helps to make sure that a project isn't too overwhelming or too high level to introduce so that students don't panic or give up so easily*.

Templeton also described benefits when discussing how academic problems primarily focus on the variables you need to solve for and how those contrasts with their experience in industry:

> *Whereas a practitioner, you need to be adept at making reasonable engineering assumptions that would allow you to calculate those things [variables], and that's the part of engineering that is sort of impossible to teach, but it's something that by pairing those two together in the problem formulation, you can at least start to broach some of skills that they'll need in the future.*

Additionally, when asked who else should be involved with the development besides the student, faculty, and practitioner, Sullivan stated that the PIs role was important:

> *I think having somebody that is well-versed in engineering education as either a facilitator or an aide is a huge advantage, because I think with just faculty, student engineer, those three personalities, all three of those together don't necessarily know how to build good education processes.*

Each participant also expressed potential disadvantages of the collaboration. Sullivan stated that integration and student motivation could make it difficult to offer a complex problem in an already complex course. Remy mentioned a similar concern when they said, “there could be the potential for [the innovation] to stray a bit away from the class or what is commonly taught in the curriculum”. Templeton expressed that as long as all parties can communicate, that they can resolve issues related to how, “a practitioner will see a problem is going to be quite a bit different than how an academic views the same problem”. Each participant raises valid concerns related to the development of an innovation. Heat and Mass Transfer is known to be a difficult course and a complex open-ended problem would need to be designed in a way that is still representative of the real problem but also palatable for students and adoptable by the faculty member. Participants agree that this collaborative process is one way to help create an adoptable problem.

The primary barrier to adoption mentioned for this study was *time*. This agrees with previous literature that states that time and resources are the primary barriers to adoption [19] . Sullivan mentioned time with respect to the availability of time in the course to offer a larger complex problem. Sullivan said, "it gets really tricky when you already feel like you've pushed as much stuff in as you can." Remy recognized that time was a barrier with respect to development and capacity in the course when they said, "I think time is probably the biggest barrier, because it takes time to do a workshop, it takes time to develop the problems. And then you have to carve out time to implement them." Remy also mentioned that student resistance could be a potential barrier but "as long as it's graded, there's incentive to get it done." Templeton agreed that time is a potential barrier and that it will also require that practitioners need to be "willing to put in the effort". Templeton stated it may be difficult for "practitioners to see the benefit individually and immediately." Templeton is describing how some practitioners may want more of an immediate payoff from their involvement in the form of recruitment. They contrast this with practitioners who are interested in the "global standpoint" of trying to educate all engineers. If more practitioners are involved in developing problems, how do we ensure that they are interested in the overall benefit to engineers globally? However, should that be a concern if students are exposed to a real problem inspired by practical experience?

Suggested improvements shared by the participants focused mostly on the timing of when the development of the problem began and the right course for the innovation. Considering that this project started in the summer prior to the fall semester that Heat and Mass Transfer was offered, the faculty member felt very motivated to adopt the problem during the following fall semester. However, after much iteration and even attempting to adopt the innovation, the faculty member realized there was not enough time or space in the course. All participants suggested starting the collaboration sooner. Additionally, the student and faculty member suggested that Heat and Mass Transfer may be too complex of a course for this scale of a practical problem. Considering the complex nature of the course, Sullivan suggested that a prior course such as Applied Thermodynamics may be a better option for a complex problem because it has more "wiggle room".

When starting the development of this innovation, the PI was hopeful something could be adopted. However, the PI underestimated the complexity of the innovation that would be developed and without wanting to restrict the development to make it fit immediately into the course structure, adoption has been put on hold until the next offering. Templeton also suggested that including engineering technicians in the development process would be beneficial because these are the people who will, "actually build or maintain the design. Each of these suggestions will be considered in the next iteration of this study.

Conclusion

This study highlights many perceived benefits and improvements for a collaborative workshop between a student, faculty member, and engineering practitioner. This is an ongoing study that will eventually broaden to include different engineering courses and engineering disciplines. The current innovation will also be finalized and adopted in the next offering of the course. The intent of this work in progress publication was to highlight key benefits and potential areas of improvement for this type of innovation development. All participants have agreed that the process was rewarding and would be beneficial to make more widespread. Additionally, all participants have agreed to continue with this research and would participate again for different innovations. This study also highlighted barriers to adoption that should be considered when revising course content. It is evident from previous research and this study that time may always be a limiting factor. The continuation of this study will include providing more time for collaboration ahead of adoption and potentially involve more stakeholders in the process. The continuation of this study will also seek out themes related to the opinions and beliefs of the participations with respect to engineering knowledge and what it means to be an engineer.

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Appendix A – Rough Draft of Learning Innovation

Real World Engineering – Cooling Rat Brains

Introduction – It is common knowledge that rats need to keep their heads cool for the survival of the species…Wait, that doesn't sound right. I think Rats are doing fine. Maybe except Pinky…

On a more serious note, this engineering problem, as laid out in the attached slides, was developed to study the effects of therapeutic hypothermia when applied to a brain that had undergone a Traumatic Brain Injury (TBI). The goal is to use cooling to minimize the long-term effects of a TBI by reducing inflammation, free radical generation and release, disruptions to the blood brain barrier, and excitotoxity. To study the effectiveness of this strategy a series of tests will be conducted using rats.

Scope – Design a brain cooling device that can maintain a temperature between 33℃ and 35℃ and be made of a conformable material that cannot deform more than 3%.
For this class, this design will be broken into three different sub-problems (Heat transfer, fluid flow, and mechanical). Engineering problems are inherently composed of multi-physics interactions that must be considered in each step of the design, but we are going to break this down in a more linear fashion and highlight the connections instead of completing a full design.

Step 1 - Heat Transfer:
Consider a simplified cooling fin array as shown in Figure 1.

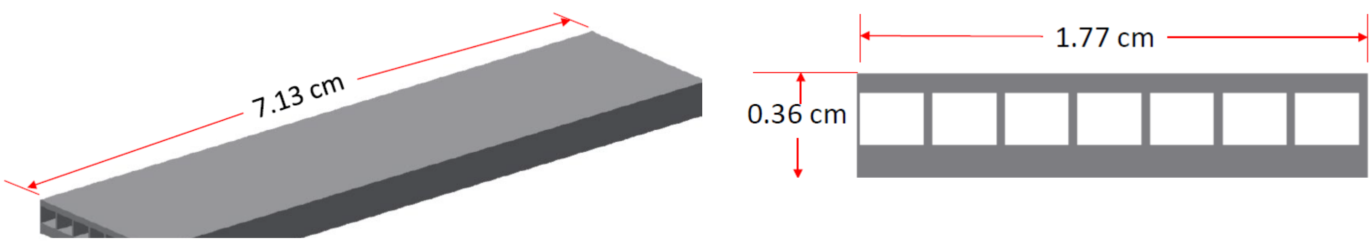

Figure 1: General cooling flow channel.

The bottom surface is exposed to the surface of the rat, and the top is exposed to the ambient environment. Assume the convection on the top surface has a heat transfer coefficient of (5 W/m^2).

Create a spreadsheet to evaluate the heat transfer from the brain that can vary:

- Number of Channels
- Channel dimensions
- Wall Thickness

*The goal is to **maximize the coolant temperature** required to achieve the design level of cooling (no need to need to pump ice water).*

Thermophysical properties of the materials involved, the heat flux from the brain, and the coolant fluid flow are provided in Table 1:

Table 1: Parameters and thermophysical properties

Coolant		
Flow rate	20	mL/min
Fluid (PGW)	60	60% Propylene glycol, 40% Water - Properties can be calculated using mass weighted averages at room temperature and pressure.
Heat Flux	0.25	W/cm^2
Channel Material		
Thermal Conductivity	0.13	W/mK
Tensile Strength	1.7	Mpa
Hardness	60	ShoreA

Head Heat Transfer

Parameter	**Brain**	**Bone**	**Scalp**
ρt [kg/m3]	1050	1500	1000
ct [J/kgK]	3700	2300	4000
keff [W/mK]	2.5	5.8	1.7

Step 2 – Fluid Flow

Using the channel design from Step 1, calculate the maximum pressure in the channel. The back pressure at the exit of the channel is fixed at 30 kPa (gauge).

Note – the optimum heat transfer design might produce increased channel pressure. Make note of any observations and continue to step 3.

Step 3 – Mechanical

Will your design hold?

1.) Sketch an exaggerated version of the deformation that you expect in the channel at max pressure. This is to identify where to focus your analysis.
2.) Using simple beam theory calculations, determine the maximum stress in your design.
3.) Determine the maximum deflection.

Comment on your findings in regard to Steps 1 and 2.