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Addressing Biomedical Problems Through Interdisciplinary Learning: A Feasibility Study*

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Interdisciplinary learning is often limited to student groups which already have significant overlap in either their curricular content or whose day-to-day duties entail regular interactions. This is not generally the case for engineers and clinicians, and almost never the case for students of engineering and medicine. In this feasibility study, interdisciplinary learning outcomes were assessed in six teams comprising undergraduate engineering and medical students at a major Irish university. Three key factors differentiated the current study from complimentary approaches; (i) the module places undergraduate medical and engineering students in interdisciplinary teams, (ii) students are educated in a systematic methodology (TRIZ) of design and innovation, which is then applied to a clinical challenge and (iii) the present study places student learning outcomes as the primary mission of the module, rather than the project deliverables. Feedback from both students and clinical mentors was assessed using focus groups and individual interviews. The learning outcomes were convincingly imparted as evidenced by feedback, which was overwhelmingly positive from both students and clinicians. As an added benefit, the tangible outputs (e.g., prototype or software tool) from each of the 6 teams represented a worthy proof-of-concept, in some cases suitable for future research or commercial exploitation. This initial feasibility study highlights the potential benefits of a new structured methodology in to solving clinical problems in the context of interdisciplinary learning.

Keywords: interdisciplinary learning; medical education; biomedical design; TRIZ, theory of inventive problem solving; TIPS

1. Introduction

Interdisciplinary learning is a well established component of the education of engineers. Common entry for engineering students is widespread amongst universities and third-level institutions in Europe and the USA. This has significant advantages for resource allocation within the university and, generally, benefits the student by avoiding specialization at a premature stage. Medical education is a graduate degree programme in the US but in Ireland, competitive undergraduate entry is more common. The medical programme in authors' institution is five years in duration. The first three years comprise a significant basic science component with clinical integration from the outset and includes a student selected option in each year which is typical of many medical curricula. To our knowledge, there is no precedent for an interdisciplinary module which couples engineering and medical students in the undergraduate setting. In this feasibility study, 6 medical and 22 engineering students were allocated to one of six interdisciplinary groups, assigned a senior clinical mentor under whose direction the group chose a real-life clinical problem to solve over a 12 week semester. There were two early withdrawals which left the final student count at 26.

The concept of clinician-mentored biomedical design is well established and has a proven track record. At Vanderbilt University, Professor Paul King pioneered the approach as the capstone project for senior biomedical engineering students [1] and the clinician-mentored senior project has become commonplace in the senior biomedical engineering curriculum of many institutions. Professor Alex Slocum's Precision Machine Design module is a more recent interpretation at MIT. This module, which is supported by the Center for Integration of Medicine and Innovative Technology in Boston, has led to commercial ventures and significant follow-on research [2]. At Harvey Mudd College, the Engineering Clinic seeks to address major clinical challenges with a team-based approach and significant resources [3–4]. Stanford University's Biodesign programme places experienced (post-doctoral level) engineers, clinicians and business experts in teams for a 12 month period with the goals of commercial product outputs [5]. Other similar programmes include the University of Minnesota's New Product Design and Business Development Course [6], Johns Hopkins University's Biomedical Device Innovation and Design Course [7] and the Postdoctoral Programme in Biomedical Engineering at Katholieke Universiteit Leuven [8]. In many of these cases, the primary focus is the project output rather than the

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pedagogical output for the students involved. The clinical problem is posed by a senior practising clinician. Also, while there are sporadic reports on the comparative advantages or anecdotal experiences associated with such programmes [12–15], there has been little or no account of the participants' feedback based on the student or clinician experience. This report aims at providing just such an account based on a limited local cohort and a site-specific study.

While the cited programmes and modules represent the state of the art in clinician-mentor problem-solving, the present study differs in three key ways:

1. The module places undergraduate medical and engineering students (electrical and electronic, civil and environmental and mechanical majors; no biomedical engineering degree exists at the authors' institution) in interdisciplinary teams.
2. Students are educated in a systematic methodology (TRIZ) of design and innovation, which is then applied to a clinical challenge but which also represents a valuable tool for their future formation as engineers and clinicians.
3. The present study places student learning outcomes as the primary mission of the module, rather than the project deliverables.

This work may be of relevance to module and programme developers within the disciplines of biomedical, electronic and mechanical engineering, as well as computer science. The findings are particularly relevant to institutions which also offer an undergraduate (or graduate) medical programme as a vehicle to embed innovation within the medical curriculum.

2. Methods

The biomedical design module concept was implemented at the authors' institution for the first time in 2011/12. The module brought together interdisciplinary teams of engineering and medical students with a consultant-level clinician at an affiliated teaching hospital.

2.1 Student selection

The module was offered as an optional 5-credit (nominally 24 taught hours) to all (i) final year electrical and electronic engineering (EEE) students, (ii) final year civil and environmental engineering (CEE) students, (iii) postgraduate mechanical engineering (ME) taught masters students, (iv) third year undergraduate medical (UM) students and (v) second year graduate entry medical (GEM) students. A target enrolment was 30 students with a 2:1 ratio of engineering to medicine. Six medical students (5 UM and 1 GEM) were enrolled with one (UM) subsequent withdrawal. The remaining five medical students were accepted to and completed the module. Over 50 engineering students expressed initial interest in the module. A combination of natural selection, early candidate withdrawal, academic record and a personal questionnaire (Readiness for Interprofessional Learning Scale or RIPL) was used to identify suitable engineering students. The questionnaire is a modified version of the RIPL questionnaire which has previously been used to assess readiness for interdisciplinary learning at the authors' institution [16]. The final enrolment (after withdrawals) of engineering students was 4 EEE students, 12 CEE students, 3 ME students. By special request, two postgraduate research (PR) students (one EEE PhD candidate and one CEE research masters candidate) were added to the enrolment bringing the total enrolment to 26 students.

2.2 Clinical mentors

The selection of clinical mentors to the student teams was made in close collaboration with the institution's School of Medicine. Six clinicians were identified, all of whom had institutionalteaching appointments. The six comprised two anesthetists and surgeons (2 gastrointestinal, one cardiothoracic and one orthopedic). Each clinician was required to make an initial "idea-pitch" to the students (Week 2) which facilitated student matching to a project of their choice. It was the student team's responsibility to arrange an initial face-to-face meeting with the mentor to discuss the design. Clinicians were encouraged to meet their team on a regular basis throughout the semester in order to provide meaningful clinical feedback on the team's design. A minimum of two further face-to-face meetings were expected. The mentor was also encouraged to attend the final design symposium and was asked to provide a grade on the team's final report and webpage.

2.3 Team projects

Each of six clinical mentors was invited to propose a possible clinical problem for evaluation at least three weeks prior to the commencement of the module for review by the module coordinator. The criteria for a suitable project were (i) meet a real clinical need, (ii) have a significant design component (i.e., not just a literature review), (iii) have commercial or humanitarian potential, (iv) challenge the students to provide the solution and (v) be of reasonable scope for a 12 week semester. This led to the identification of five unique problems. Both of the gastrointestinal surgeons returned essentially identical problems. After consultation with these two clinicians it was decided that two student teams would pursue solutions to the problem independently under the mentorship of one or other of the clinicians. Project allocation was by the student's personal ranking having listened to a 10-minute 'idea-pitch' from each of the clinical mentors. Approximately 90% of students were placed in teams to solve the problem which they ranked as 1 or 2 in preference. The final team composition was four 4 groups of 4 and 2 groups of 5 where all the teams except 1 had one medical student.

2.4 Module content

The module met for 24 hours of formal lectures in twelve 2 hour sessions, including an initial two-hour introductory session, a two-hour 'idea-pitch' (and interactive Q&A) with the clinical mentors and a two-hour 'show-and-tell' by the student teams of their design to their class and instructors (the final session). The nine remaining module sessions covered (in as much detail as was feasible), all aspects of biomedical device design (biomaterials, medical device regulation, human factor engineering, intellectual property and licensing) but with an emphasis on the application of the Theory of Inventive Problem Solving (TRIZ) to the particular design challenge of each team. A number of invited guest lecturers from industry and clinical practice were included (see Learning Outcomes).

TRIZ is a Russian acronym, *Teoriya Resheniya Izobretatelskikh Zadatch*, which loosely translates to the Theory of Inventive Problem Solving. It was first published in 1946 by Genrich Altshuller [9] and is used extensively across many different industries [9,10] and is of increasing interest to universities. In recent years TRIZ has been used to achieve breakthrough innovations in the medical devices industry. At the authors' institution, TRIZ forms a core component of undergraduate degree courses in the School of Engineering and is a component of the programme's national accreditation from Engineers Ireland. TRIZ gives teams in the Biomedical Design module the ability to construct thinking pathways which guide them to high levels of innovation. There are three distinct stages in the application of TRIZ as embodied in the current module:

1. Introduction to TRIZ. Students begin by thinking in terms of ideality where the problem (system) solves itself [10] (e.g., "my school books come to school without my carrying a school bag").
2. Ideation. Students are guided through ideation brain storming sessions with hands-on workshops and working document templates. All system resources surrounding the problem space are identified (e.g., physical space, time, clinical expertise etc.) and students identify resources that are potentially useful to the final solution.
3. Contradiction Resolution. The problem is brought to a layer of abstraction where TRIZ methods are applied. This is achieved with a fundamental tools developed by Altshuller; the Contradiction Matrix [9]. This tool allows the team to focus in on the multiple contradictions in a complex system by creating a matrix of solutions and associated primary and secondary problems each team identifies the helpful methods from the forty inventive methods inherent to TRIZ [9,10]. Physical realisability and mentor assessment of contradiction solutions were employed in selecting the optimal solution.

The results were original in most cases and solved many of the problems in an unexpected way. All the students found the approach innovative, useful and easy to learn (see Student Outcomes).

All of our interdisciplinary biomedical design teams found multiple solutions to the clinical problems and TRIZ allowed them to break elements of "physiological inertia" which retards the problem solver from thinking inventively. TRIZ facilitated generation of numerous solutions, although some of these solutions had insurmountable "secondary problems." In these cases, TRIZ was applied iteratively to some of the secondary problems to open up the primary solution and overcome the major barrier. As TRIZ encourages multiple solution. The students stepped carefully through the selection process to find the best solution and our subject matter specialists, the clinical mentors, were essential at this stage of the process.

2.5 Student assessment

Student performance in the module was evaluated as follows:

- 10% for a final group-graded symposium multimedia presentation.
- 20% for weekly design logs, webpage and bi-weekly reports including (i) User Specification Document, (ii) Market Research Report, (iii) Materials Hazard Assessment, (iv) Regulatory Assessment, and (v) Intellectual Property Report.
- 20% for a final team design report which incorporated the principal findings of the bi-weekly reports as well as four-page description of the final design.
- 10% for individual performance in an in-class written examination.
- 40% for a final written examination (medical students were exempted from the final examination and their grade weighted accordingly).

The group's webpage (WordPress-based) constituted 10% of their final group grade and was an integral way to maintain communication with the clinical mentor during the semester. Groups were encouraged to make use of graphical and video input and all design reports and assignments were required content, as well biographical data.

2.6 Learning outcomes

Learning outcomes associated with the module are outlined below (Table 1) as the methodology employed in the implementation.

2.7 Intellectual property

In keeping with the institution's Policy on Intellectual Property, all intellectual outputs from the module were to remain the property of the institution until such time as the university relinquished that right. Students were advised of this in writing prior to enrolment.

2.8 Module feedback

Module feedback derived from clinician interviews (n = 6), student questionnaires (n = 22) and focus groups (n = 7 engineering students and n = 2 medical students). Focus group outputs were analysed using constant comparison methods with a grounded theory approach [11]. After the interview content was transcribed, MS Excel® was used to manage and code the data, with concepts, themes and their properties subsequently identified. Open coding was used to deconstruct the data into meaningful phrases/sentences/words, and they were then clustered according to specific categories.

Table 1

Learning Outcome	Methodology
Describe and apply a systematic design strategy (TRIZ) to a real-world project	Students produce assigned deliverables (e.g., ideality statements, contradiction matrix, selection criteria) related to their specific problem
Describe fundamentals of IP law and patents in relation to biomedical devices	Students learn these through seminars delivered by invited guests from commercial IP law firm
Describe typical commercialisation pathways for biomedical devices	Students learn through multiple commercial case studies (clinician—and engineering—led) in the biomedical device sector
Perform a preliminary market survey to identify commercial conditions for a new product	Students produce a business model for their solution using established templates (businessmodelgeneration.com)
Evaluate the intellectual property landscape for a new biomedical concept	Students produce an IP disclosure detailing the novelty of their solution
Design a solution for a real-life clinical need	Students produce a working solution to the clinician's problem
Work in a real-world interdisciplinary environment	Students meet regularly with their team and clinical mentor in developing their solution

3. Results

3.1 Clinician outcomes

Clinician feedback (n = 6) was evaluated in post-module interviews of 30–40 minutes and the outcomes were broadly focused on two themes: perceptions of the current module ("How it works"); future development of the module ("How it develops"). With respect to the first theme—perceptions of the current module—the following sub-themes emerged:

(a) Differences between engineering and medical students—there was a general perception that engineering students engaged in an open and enthusiastic manner with clinicians during the ideation process, and demonstrated an ability to view clinical design problems from a fresh and novel perspective. In contrast, the role played by medical students within the design team appeared to be ill-defined and, in some instances, redundant. Additionally, there was a concern that their contribution would be lessened by not having received sufficient exposure to a clinical environment at this point in their medical training. Finally, it was felt that a readiness to engage with an engineering approach would only suit a limited subset of medical students;

> "They (engineers) engaged very, very frequently at the beginning, they took the initiative, they ran with these ideas" (Mike—Interview 3)
>
> "The medical student who just seemed to be a little at sea anytime we had a group session" (Sean—Interview 1).

(b) Teams—despite the prescribed requirement to rotate team leadership until week 10 of the module, it was noted that the project "drivers" typically emerged at an early stage. Teams were also a productive source of ideas and these contributions provided a useful contrast to the clinician's academic background;

> "There was one really, really good guy, who by a mile drove the project, and the other guys fell in behind him" (Mark—Interview 2)

(c) Communication—clinicians agreed that clinical constraints restricted the amount of time they spent with student teams. All agreed that scheduled meetings at regular intervals assisted goal-setting and progress evaluation;

> "Nature of the job, I am always on the run, which is a bit annoying for them as well as being for me" (Will—Interview 5).

(d) Value of concept—clinicians indicated that the concept underlying the module was excellent, and it was viewed to have a strong academic focus. With respect to student engagement and readiness to participate in the module, it was felt that students took a significant amount of personal responsibility for their projects, which may reflect a greater self-directed learning component relative to other, more didactically-focused, course modules. On the negative side, there was a concern that the module demands may exceed their abilities and expertise as undergraduates.

> "The problem is that when it came to specifics they didn't have any experience. . .The other problem that I thought is I suppose maybe we are expecting too much" (Jack—Interview 4)

With respect to the second theme - future development of the module—the following sub-themes emerged:

(a) Integration—improved integration between both students groups and their clinician supervisors within the module environment was seen an important step towards addressing differences in engagement and communication patterns (both student-student & student-clinician) between medical and engineering students. It was additionally suggested that the module be pitched at a later stage in the medical students' clinical training, and that their role in the module be more operationally defined;

> "Is this something that could be pitched a year later? When there is potentially more exposure to some of the clinical problems that would be presented to clinicians, and medical students themselves would have gained more emotional and intellectual maturity" (Sean—Interview 1)

(b) Mentoring—clinicians advised on the introduction of mentors within the module, as distinct from the role of the project supervisor. Mentors could be clinical fellows working within the hospital who would be available for advice and guidance. Other suggestions included provision of direct access to the University "technology transfer" office and resources;

> "But probably you would be better off with a . . . some sort of vehicle, comes at the end of each year's modules, is supported like a technology transfer albeit, but under a localised engineering slash level" (Mike—Interview 3).

(c) Commercialisation—while all clinicians were of the view that the module was primarily an academically-focused module, several potential avenues towards introducing a greater emphasis on commercialisation of outputs were discussed. These included the possibility of introducing industry involvement earlier in the design project, and the necessity for the university sector to promote industry-ready innovation. It was also noted that commercialisation potential would also act as an incentive for student participants, particularly the engineers;

> "If you could get that opinion and something, a market feasibility on it, then you would decide whether it was worth pushing or not" (Mark—Interview 2).

(d) Support—the importance of providing adequate support mechanisms for projects (either within or outside the academic environment, ideally both) with commercial potential was viewed as crucial to the success of the module. Potential support mechanisms mentioned were increased links and interaction with industry collaborators working in the sector, development of an interdisciplinary research cluster and forum which would promote research at the interface of medicine—engineering—business, and availability of seed funding in order to validate and test project designs with commercial potential.

> ". . . what kind of access to materials do they have? I mean it would be nice if they had some kind of, . . . how do they find out about these materials, there are obviously processes" (Jack—Interview 4)

3.2 Student outcomes

Quantitative feedback from students (n = 22) was assessed by questionnaire after module completion. A summary of these responses is included in Appendix A. The two main themes arising from the engineering student focus group (n = 7) were as follows: (i) quality of interaction between student participants ("human factors"); (ii) module characteristics including attributes and constraints ("module design"). Due to obligation to attend medical rotations, medical students who completed the module did not attend focus group sessions. Focus group questions were distributed to medical students via web-based survey invitation [hosted on surveymonkey.com, Portland, Oregon, USA]; two out of five potential respondents completed the survey.

In relation to the "human factors" theme, students commented on the positives of having team members from different backgrounds working on a particular project. Medical student involvement was generally viewed as positive. However, time restrictions due to other academic demands were perceived as impacting negatively on the medical students' ability to contribute equally to the development of the project.

> "It was quite good actually because [em], those areas, things we wouldn't have known, or be able to get over really without the medical student". (Andrew)

> "But we didn't want to pick up the slack either, that's not really fair, so we did have an awful lot of picking up for that yeah." (Tara)

Students found working with a clinical mentor to be very beneficial to their project development since the clinician was aware of what kinds of TRIZ solutions are workable in the clinical environment.

> "It was brilliant and it was great to work with a surgeon because we would never get a chance to work with someone like that." (Paul)

> "He just sent us in the right direction from the start, giving us the information that we needed or the resources that we needed to design the end product." (Colin)

Clinician feedback was perceived to be useful as a support mechanism for medical students in each team, as well as facilitating user-oriented design solutions.

> "I know it sounds like he just shot our idea down but it was good, because he said at the start that's not going to work, we had more time to devote to other things." (Tara)

There were divided opinions regarding communicating with the clinical mentor. Whilst some students prioritised face-to-face meetings in a clinical environment, others favoured email.

> "I suppose we used to go there every Friday to [the local teaching hospital], it's personal, much better than any email or phone call." (Max)

> "But in the same way, we didn't have to contact him in person much; most of it could have been covered in an email." (Colin)

Students identified a number of attractive and unique "module design" attributes: (i) promotion of creativity and freedom of expression;

> "I liked it, it was completely different to other modules we have done. I mean we do other design modules and stuff for buildings, but it's very kind of like rigid." (Tim)

> "I have never seen anything like it." (Paul)

(ii) use of ideation tools and interdisciplinary interaction to promote innovative solutions;

> "I suppose the main thing would have been the TRIZ technique that we were taught early on, and there is very, there are steps to that, going through that very methodically,..your solutions nearly just fall out of that, it was quite helpful." (Mary)

(iii) module structure, with course content during each teaching session appropriate to stage in design development;

> "We would cover a topic in class and that would help very much with the next stage of the design, yeah I think a lot of that was quite clear, pretty well defined." (Tara)

(iv) an opportunity to present design prototypes in front of an audience of clinicians, academics, and industry stakeholders;

> "But eh, presentations there, one other point, which I found very good, you are actually dealing with people from industry, hotshots that are out there, like I really thought it was brilliant." (Max)

(v) an opportunity to apply engineering solutions to "real world" clinical problems, and to obtain feedback about how they might work in a clinical context;

> "So many Pascal's [pressure] are applied to the needle as it breaks through the skin but it doesn't actually make sense until you see it (referring to the clinical setting)." (Andrew)

(vi) development of a commercialisation "mindset", including increased awareness of regulatory issues and marketability.

> "At the end of the day it has to be economically viable as well as everything else." (Max)

In general students felt that the Biodesign module has a greater workload than other modules. This was not seen as a negative by the engineering students, but they did feel that it was viewed as a negative by the medical students. They also felt that the value of clinical immersion varied depending on the nature of the design problem.

> "It was very much an optional subject for them and seen as an easier out, I think they were a bit disappointed, like our med student said that his friends had an easier subject that was taking just two hours a week." (Tara)

> "For us it probably wasn't as important (clinical immersion), ours involved pressure inside a cast and we went up once to see how a cast is put on and all that but once we came up with a solution there wasn't much point in watching more casts being put on." (Tim)

All students felt that continuous assessment and the practical nature of the module superseded the value of a pencil-and-paper end-of-year exam.

> "Also we had an exam at the end of the year but I don't think there is really a need for it." (Colin)

> "That's just one point that the end of year exams are irrelevant really." (Max)

Due to obligation to attend medical rotations, medical students who completed the module did not attend focus group sessions. Focus group questions were distributed to these students via web-based survey invitation [hosted on surveymonkey.com, Portland, Oregon, USA]; two out of five potential respondents completed the survey. Medical students indicated that clinical placement commitments and academic workload limited both their engagement with the module and, in particular, their appreciation of the utility of the TRIZ process.

Additionally, while they enjoyed the opportunity for interaction with clinical mentors, they commented that observing the clinical problem in a clinical context added little to the design process - it might be expected that engineering students might gain more from this experience than their medical colleagues. Finally, while they enjoyed working with the engineering students, it was indicated that the most valuable interdisciplinary interaction occurred with electrical or biomedical, rather than civil, engineering students.

3.3 Project outcomes

At the end of twelve weeks of structured lectures, a number of individual team meetings and an estimated 20–30 additional hours of student design work per team, six independent design solutions to five clinical problems were proposed. In this feasibility study, the work did not represent a capstone project. A selection of the solutions are illustrated in Fig. 1 including (a) an automated fracture recognition algorithm for x-rays, (b) a pressure-sensing needle for epidural administration, (c) a closed-cast pressure monitor and (d) a 3D varicose vein imager capable of working with standard ultrasound technology. The design selection pathway for one of the teams is included as a case study in Appendix B.

The design adjudged to have the most commercial and clinical potential by a panel of independent experts from industry and academia at the final design symposium was a laparoscopic retractor for small bowel resection and this team (self-titled SecuRetract) were awarded the inaugural John Francis Burke Prize for Biomedical Innovation at the authors' institution. Subsequently, SecuRetract has also been awarded commercialisation funding through the government-funded Enterprise Ireland organisation, which will see the device pursued as a commercial product.

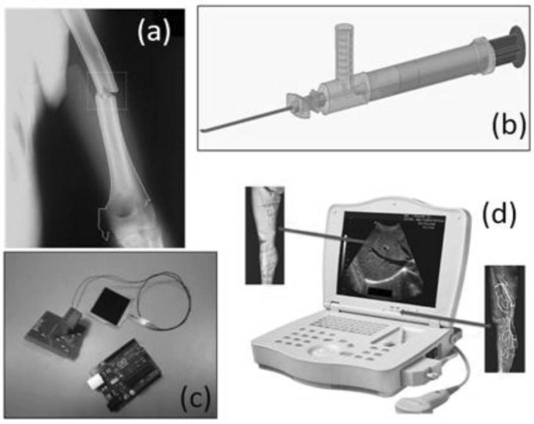

Fig. 1. Examples of the project outputs from the interdisciplinary biomedical design module in 2011/12 included (a) an automated fracture detection algorithm for orthopaedic fractures, (b) a 'smart' needle suitable for epidural procedures, (c) an integrated monitoring device for pressure sensing in closed casts and (d) a 3D reconstruction tool for the greater saphenous vein using standard ultrasound technology.

4. Conclusions

This initial feasibility study highlights the potential benefits of a new structured methodology in to solving clinical problems in the context of interdisciplinary learning. The study supports the application of the Theory of Inventive Problem Solving (TRIZ) as an effective methodology for introducing inventive thinking and innovation into the design of a new biomedical concept. All students involved in the study valued the tool as a learning outcome, of benefit for their future careers as well as the Biomedical Design Module.

The study also outlines how a successful, innovative interdisciplinary approach at the authors' institution, which places medical and engineering students in interdisciplinary teams, may be further optimized. In particular the learning benefits to medical students might be improved seeking their involvement at a later point in their programme. The initial indication from this feasibility study is that the methodology of systematic innovation is a useful tool in countering inertia associated with interdisciplinary learning. The programme will continue to be offered at the authors' institution. Finally, while the primary focus of the Biomedical Design module is pedagogical, the level of achievement of the student teams has been to such a standard as to validate external future investment in at least one of the devices developed. A more coherent and coordinated concept exploitation strategy should be implemented which might facilitate retaining students to further develop the concepts from the module. We are keen that our initial positive experience and lessons learnt in the delivery of this novel module be shared so that similar ventures can be considered elsewhere.

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Appendix A: Quantitative Student Feedback.

In addition to qualitative feedback, quantitative student feedback was assessed by questionnaire post-module completion. Selected responses from 22 students are shown in Fig. 2.

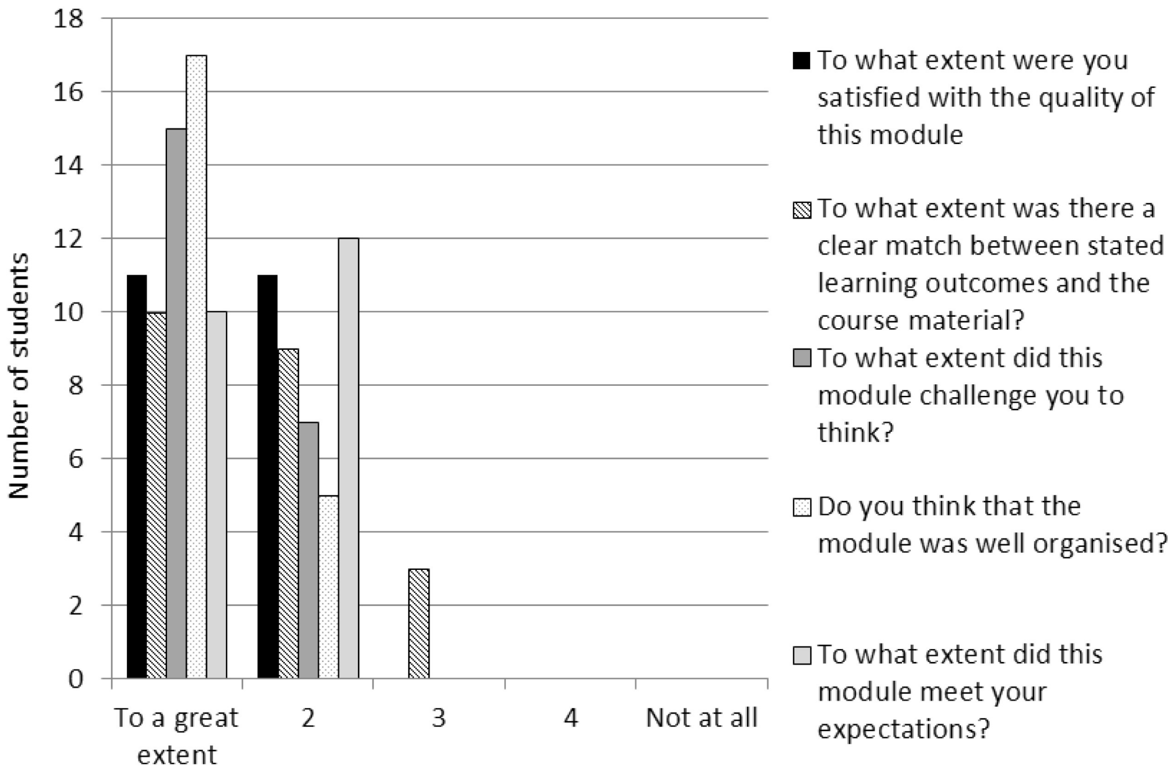


Fig. 2. Quantitative student feedback evaluated by post-module questionnaire.

Appendix B: Final Design Selection Case Study

This case study represents the pathway followed by the one of the two teams investigating a solution to laparoscopic surgical retraction. The first assignment examined high-level use of TRIZ to identify system resources. The system resources are presented in Fig. 3. The next stage involved a problem statement which succinctly summarised the clinical challenge. This team's problem statement was "to reposition abdominal organs during keyhole surgery." The resultant ideality statement captured the ideal solution as "small bowl does not obstruct abdominal surgery." The TRIZ list of all possible inventive principles of use in this task was then employed to arrive at an unbiased list of design solutions. These were ranked according to team-selected design parameters to determine a final solution, as indicated in Fig. 4. Contradictions were addressed where

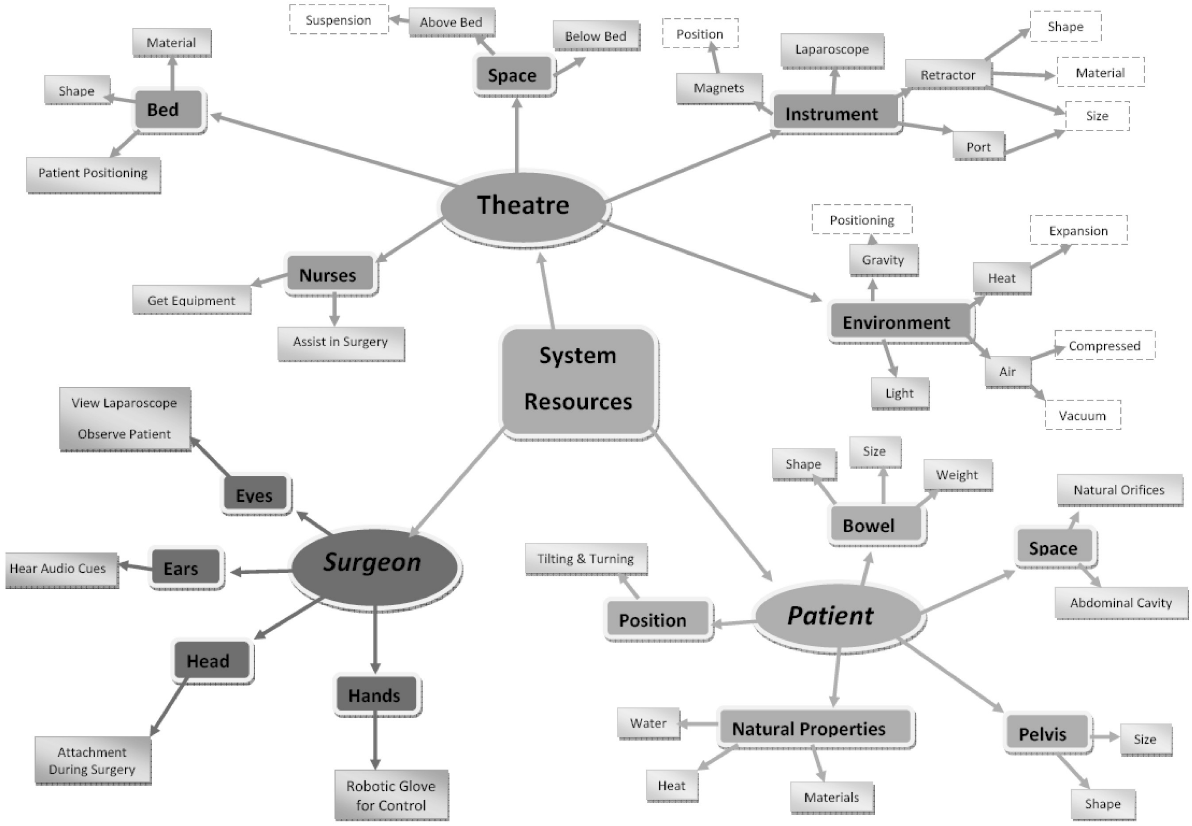
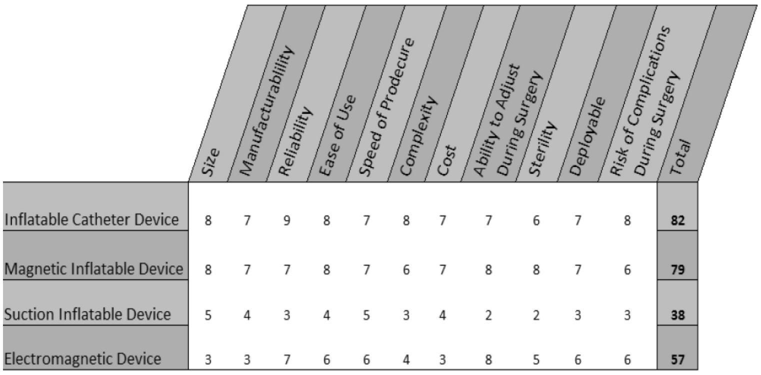


Fig. 3. System resources were initially categorised in a meaningful way by each of the teams. The output from one of the two teams investigation laparoscopic surgical retraction is shown here.



	Size	Manufacturability	Reliability	Ease of Use	Speed of Prodecure	Complexity	Cost	Ability to Adjust During Surgery	Sterility	Deployable	Risk of Complications During Surgery	Total
Inflatable Catheter Device	8	7	9	8	7	8	7	7	6	7	8	**82**
Magnetic Inflatable Device	8	7	7	8	7	6	7	8	8	7	6	**79**
Suction Inflatable Device	5	4	3	4	5	3	4	2	2	3	3	**38**
Electromagnetic Device	3	3	7	6	6	4	3	8	5	6	6	**57**

Fig. 4. The idea selection matrix measured all possible solutions (left column) versus design parameters of interest (top row) and ranked the solutions from 1 (worst) to 10 (best). Design parameters were problem-specific and at the discretion of the team. The solution with the highest score was then selected for further investigation, end-user feedback and, eventually, prototyping. The chart shows the selection criteria matrix for one of the two teams investigating laparoscopic surgical retraction.

Fig. 5. The inflatable catheter device prototype was the final design selected by one of the two teams investigating laparoscopic surgical retraction.

present with the aid of the TRIZ contradiction matrix. Feedback from the clinical mentor was critical at this stage of the design selection process before a final design solution was selected. The team's final prototype device is shown in Fig. 5.

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