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A Systematic Review of Mechatronic-based Projects in Introductory Engineering and Technology Courses

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Abstract

For well over two decades, engineering and technology educators have been deploying hands-on project-based learning activities in freshmen courses, in the hopes of inspiring students,increasing retention, and creating better educated graduates. Some of these educators have also been reporting the results of their efforts through papers published and/or presented in a widevariety of settings. In an attempt to understand the broad results of these efforts, this paper discusses the effects of mechatronic-based projects on the retention of engineering and technology students. To facilitate this discussion, we conducted a systematic review of well over 120 related sources of literature spanning the years from 1990 to 2014. This effort constituted a configurative review and allowed us to construct a methodically mapped landscape of the topicby applying a code or codes to each source. We will present the results of this effort, including abulations of the works that allow identification of the trends and gaps in the literature specific to the categories of Course Level, Content Delivery Method, Retention, Investment Level/Duration, Improvement Process, and Pedagogy. We will discuss our categorization strategies, and present conclusions about the efficacy of these approaches and the areas that appear most fruitful for additional research. In so doing, we hope to lay a strong foundation for future efforts towards improving the education of freshman technology students at a large land-grand, research-based university in the United States.

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Engineering Education | Higher Education

A Systematic Review of Mechatronic-Based Projects in Introductory Engineering and Technology Courses

Mr. John R Haughery, Iowa State University

John Haughery is currently a PhD graduate fellow in the department of Agriculture and Biosystems Engineering at Iowa State University pursuing a degree in Industrial and Agricultural Technology. His technical experience and interests include electrical energy systems, industrial controls, and mechatronics. Currently he is researching the integration of mechatronic-based projects into freshman engineering and technology curricula with the intent of increasing student engagement. John received his BS in Industrial Technology: Electronic/Control Systems from Millersville University of Pennsylvania in 2006, after which he spent over eight years as a control systems engineer and project manager at Multi-Dimensional Integration. Most recently, he received his MS in Engineering and Technology Management from Morehead State University in 2014.

Dr. Dave Raj Raman, Iowa State University

Raj Raman is Professor and Associate Chair for Teaching in the Agricultural and Biosystems Engineering (ABE) Department at Iowa State University, where he is also University Education Program Director and Testbed Champion for the NSF Engineering Research Center for Biorenewable Chemicals (CBiRC), Director of Graduate Education for the Interdepartmental Graduate Minor in Biorenewable Chemicals, and Education Programs Co-Leader for the USDA-AFRI project CenUSA Sustainable Production and Distribution of Biofuels for the Central USA. He is a licensed Professional Engineer who earned his BS in Electrical Engineering from the Rochester Institute of Technology and his PhD in Agricultural and Biological Engineering from Cornell University. Prior to coming to Iowa State in 2006, he was a faculty member at the University of Tennessee for over twelve years.

Raman enjoys teaching and has taught courses including freshmen engineering (mechanics and computer programming – to classes ranging in size from 20 to 500+), sophomore and junior level courses on mass and energy balance applications to biological systems engineering, numerical methods, electric power and electronics for technology students, senior design, as well as a long-standing residential/online graduate course on the fundamentals of biorenewable resources and technology. He believes well trained, curious, thoughtful people are crucial to a university's research effort, and similarly to the function and survival of society. For this reason, the overarching goal of his teaching is to impart the core content needed by the students, and to do so while encouraging inquisition and higher levels of thought. He has secured competitive funds to support his teaching efforts – from university, industry, and federal sources – and for his efforts has received departmental, college, and national teaching honors including the Farrall Young Educator Award given by the American Society of Agricultural Engineers, and an invitation to participate in the National Academy of Engineering's 2013 Frontiers in Engineering Education Conference.

Raman chairs the ABE Engineering Curriculum Committee and in that role oversaw the successful 2012 ABET accreditation visit for both the Agricultural Engineering (AE) and Biological Systems Engineering (BSE) degree programs. Upon arriving at ISU in 2006, he led the development of the BSE program, and this program now enrolls over 80 students. Raman also runs multiple summer research internship programs through his roles in CBiRC and CenUSA. In his role as Pyrone Testbed Champion for CBiRC, Raman and his students have developed early-stage technoeconomic models of bioprocessing systems. His graduate students have gone on to faculty positions at Purdue and the University of Georgia, and to engineering leadership positions at companies including Cargill, Nestle, and Merck.

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Abstract

For decades, engineering and technology educators have been deploying hands-on project-based learning activities in freshmen courses, in the hopes of inspiring students, increasing retention, and creating better educated graduates. Some of these educators have also been reporting the results of their efforts through papers published and/or presented in a wide variety of settings. To understand the broad results of these efforts, this paper attempts to answer the research question: "What are the central themes in the literature related to mechatronic-based projects and engagement of first-year engineering and technology students?" To facilitate this discussion, we collected 402 published articles spanning the years from 1990 – 2014, of which 137 were selected as directly applicable to our topic. This effort constituted a configurative review and allowed us to construct a methodically mapped landscape of the topic by applying a code or codes to each source. In this meeting paper we will present the results of this effort, including tabulations of the works that allow identification of the trends and gaps in the literature specific to the categories of *Course Level, Content Delivery Method, Retention, Investment Level/Duration, Improvement Process*, and *Pedagogy*. We also discuss our categorization strategies, and present conclusions about the efficacy of these approaches and the areas that appear most fruitful for additional research. In so doing, we hope to lay a strong foundation for future efforts towards improving the education of freshman technology students the Department of Agricultural and Biosystems Engineering at Iowa State University.

Background

For decades, engineering and technology educators have been deploying hands-on project-based learning activities in freshmen courses, in the hopes of inspiring students, increasing retention, and creating better educated graduates. These efforts are well aligned with Papert and Harel's concept of *constructionism*[1], in which students play an active role in learning by making or creating a tangible artifact. According to Verner and Ahlgren, mechatronic-themed projects are an especially palpable example of this[2]. It is therefore no surprise that mechatronic activities have been implemented in a variety of science, technology, engineering, and mathematical (STEM) curricula, particularly electrical, mechanical, and computer fields. The scope of these activities has ranged broadly from stand alone content modules to complete course implementation culminating in applied projects where students are engaged to exhibit a mastery of a variety of course outcomes.

In an attempt to understand the broad results of these efforts, this paper addresses the research question: "What are the central themes in the literature related to mechatronic-based projects and engagement of first-year engineering and technology students?" To facilitate this discussion, we collected 402 published articles, of which 137 were selected as directly applicable to our topic.

In the following sections we will present the results of our systematic review of the literature. This review is based on the methodological constructs of Gough, Oliver, and Thomas[3]. We will also include tabulations of the trends and gaps in the literature germane to our research question, discuss our categorization strategies, present conclusions about the efficacy of these approaches, and discuss areas that appear most fruitful for additional research. In so doing, we hope to lay a strong foundation for future efforts towards improving the education of freshman engineering and technology students in the Department of Agricultural and Biosystems Engineering at Iowa State University of Science and Technology.

Methods

The main components of our methodology included *Database and Search Term Selection, Data Collection,* and *Data Evaluation*[4-5]*,* as depicted in Figure 1. As we moved through each phase, incongruous articles were *excluded* (removed) and relevant ones were *included* (retained). This systematic approach produced a final product comprised of literature germane to mechatronic projects and the engagement of first-year engineering and technology students.

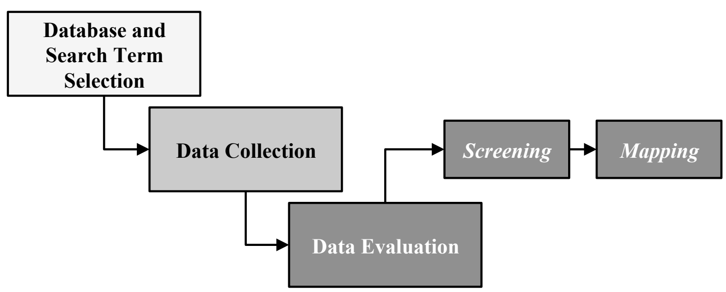

Figure 1. Overview of review strategy used in this systematic review.

Database and Search Term Selection

The databases identified in Table 1 were selected by virtue of a qualitative analysis based on the breadth of their content collection and the ease of their user interface (specifically for performing advanced queries). Additionally, these electronic databases afforded easy integration into our document management software, thereby giving us a systematic and traceable process of filtering, including, excluding, and rating each piece of literature.

Next, it was important to select a list of appropriate search strings with which to query the aforementioned databases. These strings, also found in Table 1, were used during our *Data Collection*. We employed a mixed-methods approach by selecting both precise and sensitive search terms. The expressed intent of using this mixed-method was to maximize the quality and quantity of relevant articles returned from each database[3].

It is important to note that the search term "robot" (and all of its variants) was not included as a search term. The reason being that it was overly sensitive, even when used within *Title* searches (e.g. removing this term reduced one search from 534 to 131). Also, it was observed that a majority of the irrelevant query results were related to advanced robotic research or medical robotic research, which was not within the scope of this review.

Table 1. Search terms, strategies, and article counts for selected databases. Asterisks (*) indicate the used a truncated wildcard search algorithm. Note: total articles equals 402 with 359 unique.

Database	***Precise Search Terms***	***Count***	***Sensitive Search Terms***	***Count***	***Duplicates***	***Unique***
Web of Science	TOPIC: (mechatronic* or microcontrol* or micro control*) AND TOPIC: (problem or project based) AND TOPIC: (engineer* or technol*) AND TOPIC: (course or class or curricula*) NOT TOPIC: (medicine* or health* or surgery* or design or simulation)	70	TITLE: (mechatronic* or microcontrol* or micro control*) AND TITLE: (course or class)	131	8	***193***
Google Scholar	*(search did not return reliable data)*	–	TITLE: (mechatronic AND microcontroller AND course AND class)	122	6	***116***
ERIC	TOPIC: (mechatronic* or microcontrol* or micro control*) AND TOPIC: (problem based learning) AND TOPIC: (engineer* or technol*) AND TOPIC: (course or class or curricula*)	27	TOPIC: (robot* or microcontrol* or micro control*) AND problem based learning	52	29	***50***
	Totals	97		305	43	***359***

The final component of our *Database and Search Term Selection* was to select an appropriate publication date range. We chose the range of 1990 – 2014, with a rationale based on a qualitative and quantitative analysis of publication dates of our search results. Qualitatively, it was observed that very few results were returned with dates prior to 1990. To quantitatively support this, the frequency distribution of publications per year in Figure 2 was generated using a sensitive search strategy within Web of Science in conjunction with its Citation Report tool. Based on this report, all sources published prior to 1990 were screened on title and found to be either a United States Patent filing or a medical related article. In short, none were relevant to mechatronic-based projects in undergraduate freshman engineering and technology courses and were therefore not considered as part of this systematic review. Based on this analysis, our strategy only included articles from 1990 – 2014.

Data Collection

Each source of literature collected, and the findings within, served as data points in our review. To that end, specific counts of articles returned from each database are included in Table 1. At the conclusion of our data collection stage, the total count of articles was 402, of which 43 were found to be duplicates. This reduced the total count to 359 unique, which represented the scope of articles used in the remainder of our review. In the next section we will discuss how each of these sources were evaluated and used to answer our research question. This is intended to support our conclusions by presenting a transparent methodology.

Data Evaluation

As previously alluded to, the *Data Evaluation* process of our review involved two stages. We conducted each of these at strategic points in the review process with the intent of reaching a distilled list of sources relevant to answering our research question. The results of these stages are described in the next section and illustrated graphically in Figure 3. This figure illustrates the systematic progression of our review's distillation process.

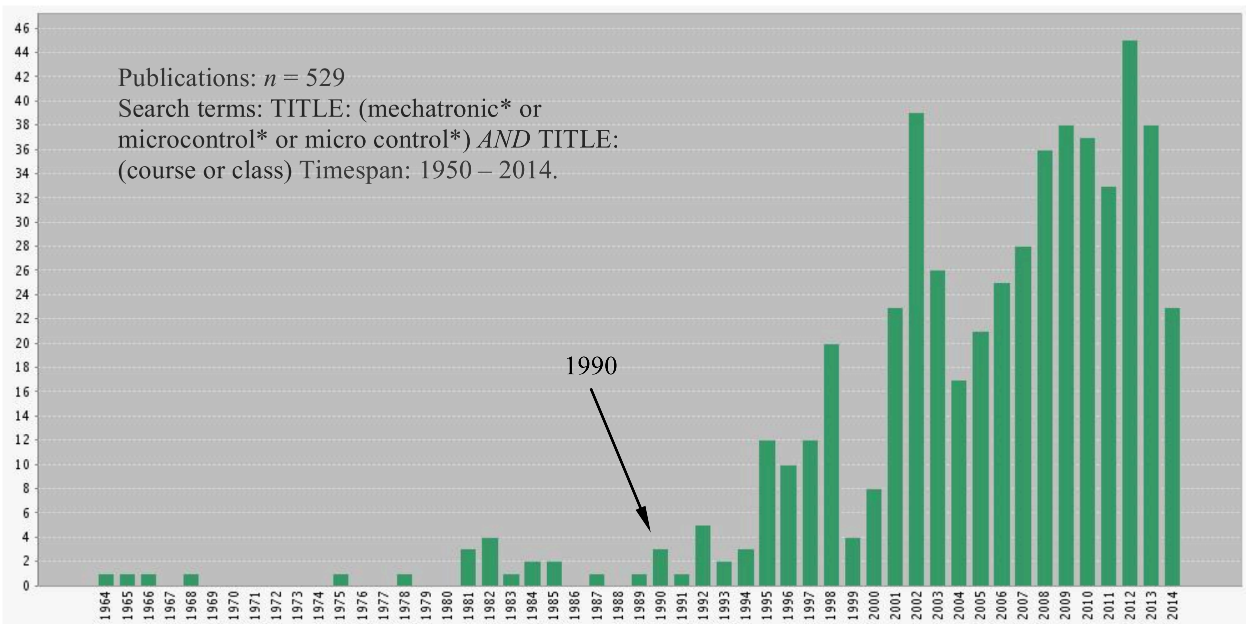

Figure 2. Frequency distribution of preliminary search results by publication date. (*Source*: Web of Science).

Results

Screening

At the outset of the first evaluation phase, 359 sources were vetted based on title and abstract information. The result of this screening was roughly a 56% reduction in our data set leaving 156 articles. The codes used to make the exclude decisions during this stage are listed in Table 2, along with the corresponding counts of articles assigned each code. If an article qualified for one or more of the exclude codes, it was excluded. If no exclude codes were given, by default an include code was applied and it was carried forward to the next stage. Additionally, these codes (and those used throughout our review) were not mutually exclusive. By coding each study, non-pertinent articles were filtered out, leaving only those applicable to our research question.

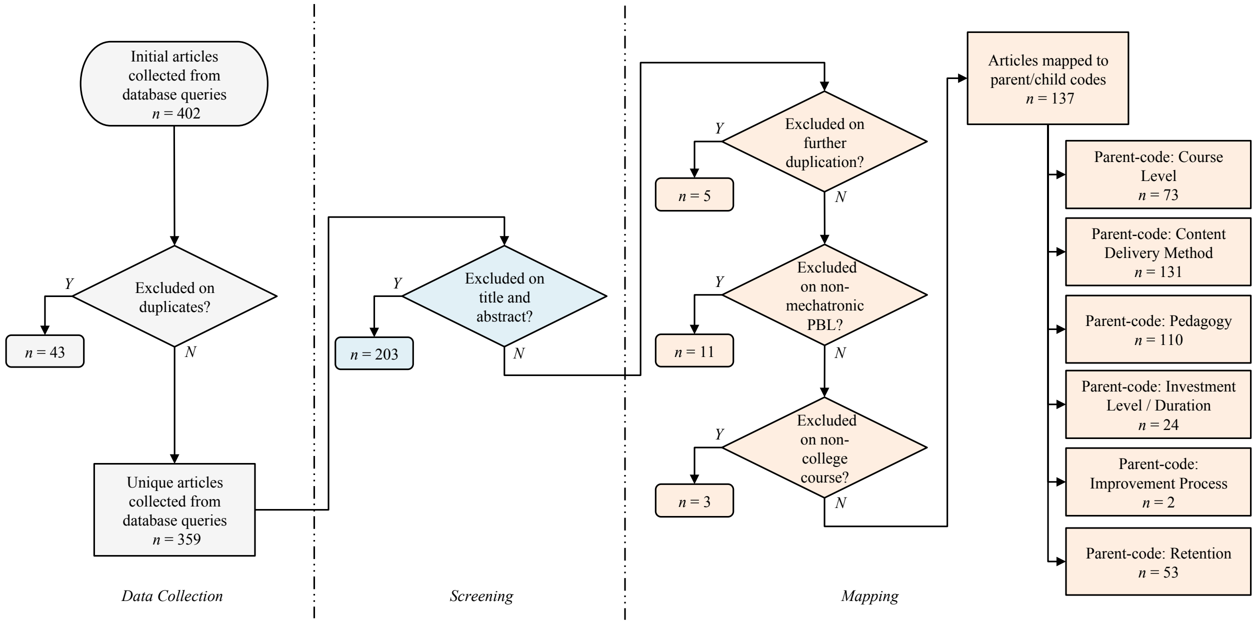

Figure 3. Flow diagram of the review's *Data Collection* and *Data Evaluation* results.

Table 2. Non-mutually exclusive codes used during *Screening*.

Codes	***Count***
Exclude on patent	32
Exclude on studies not for college courses	88
Exclude on mechatronics not used for Project Based Learning (PBL)	191
Include on absence of Exclude code(s)	156

Mapping

The purpose of this phase was to allow us "to describe the nature of [the] field of research" relative to mechatronic projects in first-year engineering and technology courses[3]. This process involved sorting the remaining included articles into appropriate themes manifested in the literature. These themes were identified with a set of defined parent- and corresponding child-codes. The specific codes used were based on a combination of our familiarity with the source articles and the scope of our research question. Table 3 illustrates the re-occurring themes based on our review process. The parent-codes identified by our mapping included *Course Level, Content Delivery Method, Retention, Investment Level/Duration, Improvement Process,* and *Pedagogy*. Corresponding to each of these were multiple child-codes, also included in Table 3. These child-codes represent sub-divisions within parent-codes.

Table 3. Results of mapping 137 sources salient to mechatronics in a college course. Child-codes not mutually exclusive.

Parent-code	***Child-code***	***Count***	***(%)***
Course Level	Graduate	19	*(14)*
	Junior/Senior	26	*(19)*
	Freshman/Sophomore*	28	*(20)*
Content Delivery Method	Module	12	*(9)*
	Remote (Online)	12	*(9)*
	Lab	17	*(12)*
	Program (Curricula)	26	*(19)*
	Course	64	*(47)*
Pedagogy	Active Learning (Group-Based)	11	*(8)*
	Reflections on Methods	31	*(23)*
	Experiential Learning (Project-Based)	68	*(50)*
Investment Level/Duration	Support: Grant	0	*(0)*
	Preparation Time	2	*(1)*
	Support: Institution	2	*(1)*
	Material Cost	8	*(6)*
	Support: Industry	12	*(9)*
Improvement Processes	Accreditation-based Improvement	0	*(0)*
	Continuous Improvement	2	*(1)*
Retention	Gender Related*	1	*(1)*
	Persistence*	2	*(1)*
	Freshman*	4	*(3)*
	Self-efficacy*	4	*(3)*
	Performance (Follow-forward)*	14	*(10)*
	Engagement*	28	*(20)*

*Codes identified as the focus of future research

It should be noted that during our thorough mapping process of all 156 studies, additional exclusion decisions were made on 19 sources. Specifically, Table 4 illustrates the quantity of articles excluded bases on corresponding exclusion codes. This reduced the total article count to 137 pertinent to our review.

Table 4. Additional sources excluded during the *Mapping* phase based on corresponding codes.

Code	***Count***
Excluded on duplicate	5
Exclude on mechatronics not used for Project Based Learning (PBL)	11
Exclude on studies not for college courses	3
Total	**19**

Discussion

By mapping the relevant themes across all 137 included studies, we were able to configure a summary of the literature so as to highlight those articles that were most salient to our research question[3]. From this process, we identified six parent-codes (themes) and 24 child-codes (sub-themes) in the literature.

When we look at the parent-code of *Course Level* in Table 3, it is evident that mechatronic projects have been implemented in courses ranging from freshman to graduate level. This illustrates the robustness of the topic to be applied to all levels of undergraduate and graduate education. Additionally, a wide variety of *Content Delivery Methods* were present in the literature. Again, Table 3 illustrates these methods spanning from individual modules to full program curricula, with a surprising number (12) offering remote online delivery formats. As expected, there were a significant number of studies depicting *Pedagogy* strategies relative to the use of mechatronics projects. Looking at the theme of *Investment Level/Duration* and the sources of support for mechatronic projects, an overwhelming number of the studies indicated industrial partnerships. This is encouraging, especially from the perspective of forming mutually beneficial affiliations between academia and industry. In contrast, only a few studies were found to implement mechatronic projects into a program improvement process, both continuous and accreditation-based. Finally, the theme of *Retention* had the largest number of child-codes, which was not surprising. As Geisinger and Raman illustrate in their systematic review of this topic, it is a multifaceted issue[6]. It is interesting therefore, to see that a large portion of the literature indicates that mechatronic projects are being used to reduce attrition of engineering and technology undergraduates.

Analyzing the child-codes identified in Table 3, it is clear that *Experiential Learning (Project-Based)* and *Course* were both mapped to the largest percentage of the 137 studies, at 50% and 47% respectively. These high percentages are not surprising, as the search strategy we employed specifically included the terms “problem or project based” and “course or class”. Further examination of our data reveals the child-codes of *Reflections on Methods*, *Freshman/ Sophomore*, *Junior/Senior*, *Engagement*, and *Program (Curricula)* were each applied to roughly 20% of the articles. The remaining 17 child-codes applied to the fewest percentage of studies, each with values below 15%. This analysis is helpful from one perspective, but to stay aligned with the purpose of our research, we were interested in themes that could be used to answer our review question. Therefore, the articles associated with the codes of *Retention* and *Course Level* were of highest importance to us, as discussed in the next section and are noted by asterisks in Table 3.

Future Work

The articles mapped to the parent-codes of *Retention* and *Course Level* will be further analyzed to extend our research towards a fuller synthesis of the significant results and findings within the literature. This synthesis will entail a quality appraisal of each and an in-depth thematic synthesis. The results will look to culminate in an analytical synthesis to produce original knowledge in this field. The intent will be to characterize existing literature explicit to mechatronic projects and student engagement in first-year engineering and technology courses. Furthermore, this will also lay the foundation for future improvements in the education of freshman technology students in the Department of Agricultural and Biosystems Engineering at Iowa State University.

Conclusion

In this paper we have attempted to lucidly present the methodology employed by our systematic review. Starting with a list of 402 studies, we distilled this down to 137. Across these final articles, we identified 6 major themes and 24 sub-themes, as depicted in Table 3. We feel these depicted the central themes in the literature related to mechatronic-based projects and engagement of first-year engineering and technology students.

Illustrating our methods, we started with a clearly defined search strategy in Table 1 and a systematic depiction of our *Data Collection, Screening,* and *Mapping* in Figure 3. By employing this methodology, we arrived at a distilled list of themes in the literature. From these results we earmarked seven themes for additional analysis in the future. This analysis will include a quality appraisal, thematic synthesis, and analytical synthesis process to arrive at a novel characterization of the literature surrounding mechatronic-based projects and student engagement in first-year engineering and technology courses.

References

1. Papert, S., & Harel, I. (1991). Situating Constructionism. In *Constructionism.* Ablex Publishing Corporation.
2. Verner I, M., & Ahlgren D, J. (2004). Conceptualising educational approaches in introductory robotics. *International Journal of Electrical Engineering Education , 41* (3), 183–201.
3. Gough, D., Oliver, S., & Thomas, J. (2012). *An Introduction to Systematic Reviews.* London, UK: Sage.
4. Dixon-Woods, M. C. (2006). Conducting a critical interpretive synthesis of the literature on access to healthcare by vulnerable groups. *BMC Medical Research Methodology , 6* (35).
5. Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields. *Journal of Engineering Education , 103* (1), 45-76.
6. Geisinger, B. N., & Raman, D. R. (2013). Why They Leave: Understanding Student Attrition from Engineering Majors. *International Journal of Engineering Education , 29* (4), 1-12.