PERCEPTION ON THE NATURE OF CORE UNIVERSITY MATHEMATICS MICROWORLD-BASED COURSES

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Abstract

We explore how, in a mathematics department and independently from constructionism and microworld literature, a sequence of core microworld-based courses came to life, and how students, teaching assistants, individual faculty, and the department have perceived the nature of these courses. Results of our exploratory study, grounded in over a decade of implementation, show that the written curriculum aligns with the implemented curriculum, or that the original vision and the students' views (survey, N=56) on the nature of the mathematics courses align.

Keywords: university mathematics, core course, microworld, students' views, exploratory objects

1. Introduction

Although the world of communication, technology and information is changing rapidly Hillel, reporting on the deliberations of the Working Group on "Trends in Curriculum" at the ICMI Study on Teaching and Learning of Mathematics at the University Level [1] states,

> A fairly accurate picture of undergraduate mathematics is that, by and large, it is still dominated by the 'chalk-and-talk' paradigm, a careful linear ordering of course content, and assessment that is heavily based on final examination. Even the highly publicized 'computer revolution' has not really made a sweeping impact on mathematics. … That said mathematics in 1999 looks a lot more like mathematics in 1939 than is the case with any of its sister sciences. (p.64)

Hillel [1] also reports that,

> Steen has written that 'strong departments find that they replace or change significantly half of their courses approximately once a decade' and 'as new mathematics is continually created, so mathematics courses must be continually renewed' (Steen 1992) [2]. These on-going updates to the curriculum can be regarded, in a sense, as 'deterministic' aspects of curriculum change, ones that do not put into question the purpose, goals, and means of undergraduate education. (p. 61)

It is our experience (Muller) that new courses added and old courses dropped generally reflect the interests of faculty members in a mathematics department and, further, these courses fall in the category of elective courses in students' programs. On the other hand, significant questions about a mathematics department's core or required courses that should focus on "the what of mathematics" are rarely taken into account; for example, the radical changes in social and economic environments, the extensive use of mathematics simulations in other disciplines, and the impact of evolving communications or of technologies are not addressed. Hoyles and Noss [3], commenting on what such dialogues should involve, state:

> Like Kaput, we noted that the incorporation of technologies into mathematical learning almost inevitably brings to the fore a range of key questions – particularly those concerned with transformation of the what of mathematics rather than merely the how – precisely because digital technologies disrupt many taken-

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> for-granted aspects of what it means to think, explain and prove mathematically and to express relationships in different ways. (p. 87)

In 2000 the Department of Mathematics and Statistics at Brock University (Canada) addressed not only the 'how' but also the 'what' of mathematics in its core undergraduate mathematics program. Doing so led to the development of a philosophy for teaching and learning and a change to a new program, called *Mathematics Integrating Computers and Applications* (MICA), which included the addition of three non-traditional innovative core courses called MICA I-II-III [4]. In [5], we have provided an overview of the MICA program stressing that it *"values allocating time in class for the students to develop and explore conjectures, to put forward arguments, to discuss and develop their logic, and to trace their own problem solving processes*" (p. 64). And furthermore, that the MICA I-II-III courses "*provide opportunities for students to use their creativity and to also develop intellectual independence [while] they develop and implement their own [Exploratory Objects]*" (p. 64). More precisely, students in MICA courses learn to design, program, and use interactive and dynamic computer-based tools, i.e., *Exploratory Objects* (EOs), for systematically investigating a mathematics concept, theorem, self-stated conjecture or real-world situation [5]. By the end of his/her undergraduate studies, each student will have created at least fourteen EOs [6-7].

The MICA courses did *not* evolve out of the constructionist movement [8]. They were the brain-child of mathematician Bill Ralph, which were then endorsed by the Department [4]. Recently, however, as a result of a literature review [9] that, building on a task analysis [10], classified the EO learning activity across five different areas in university education and identified competencies, we have characterized EOs as a 'microworlds type' [9,11]. We realised that the MICA courses may contribute to the dialogue in both Constructionism and Microworlds [8] as they provide an example, possibly the only instance, of sustained core implementation in university mathematics. But then, how are these courses perceived or even defined by the Department?

In this paper, we report on our exploratory study regarding the sequence of core microworld-based mathematics courses (i.e., MICA I-II-III) came to life and how the nature of these courses has been perceived (e.g., by the teaching faculty and students). This study evolved from a preliminary survey study of MICA students' perceptions of the nature of the MICA I-II courses, which aimed at empirically testing our theoretical results [9] involving the following five areas in university education selected based on insightful reflection: i) mathematics learning through using simulations ('*simulation*'); ii) mathematics learning through using and modifying simulations ('*open simulation*'); iii) mathematics learning through programming ('*programming*'); iv) learning experimental mathematics ('*experimental math*'); and v) inquiry-based learning of mathematics and science ('*inquiry-based*'). Building on the experiences of over a decade of sustained implementation, our study addresses the following research questions:

- *How did Bill Ralph, faculty from the Brock Department of Mathematics, come to propose, independently from the constructionism and microworld literature [8], a series of core microworld-type courses (MICA I-II-III) in its undergraduate program?*
- *How do the Department, teaching faculty, teaching assistants, and students perceive the nature of the MICA courses? And has their perception evolved since their creation in 2000?*

2. Methodology

This mixed-method exploratory study involves two parts. In the first, a voluntary and anonymous on-line survey was conducted during laboratory sessions of the MICA I-II courses in March 2013, to seek the views of students and teaching assistants regarding the nature of MICA courses. The questionnaire contained three sections. Section 1 focused on the demography of the respondents; Section 2 inquired about students' views on the nature of the MICA courses; and Section 3 questioned their views on competencies developed in these courses (reported in [12]). Questions in the latter two sections were based on our theoretical results [9]. In Section 2 students were asked an open-ended question requiring them to describe the MICA courses to a fictitious student from another institution; followed by five point Lykert scale questions about each of the five areas involved in the literature review study [9]; and one additional question on a more traditional mathematics activity, that is 'proof writing'. Questions were presented linearly without opportunity to return to a previous section. For example, the question for MICA II student participants related to *open simulation:*

> The [MICA I] and [MICA II] courses have involved me using and modifying mathematical simulations by manipulating, adding or deleting, suitable inputs (i.e., parameters) of a model and observing the corresponding outputs. (Strongly Agree; Agree; Neutral; Disagree; Strongly Disagree)

and the question to teaching assistant participants related to *programming*:

> The [MICA I] and [MICA II] courses involve students solving mathematical problems through using computer programming. (Strongly Agree; Agree; Neutral; Disagree; Strongly Disagree)

In this paper, we only report on the survey results related to the nature of MICA courses (Section 2 of survey). For student participants, the results from the six Lykert-scale questions were analysed using simple descriptive statistical methods. Mann Whitney and Kruskal-Wallis non-parametric tests were used to identify significant statistical differences between groups of participants. Qualitative data from the open-ended question was examined using the emerging theme approach followed by a word frequency analysis using Wordle [13]. In total, 56 MICA students participated in the study (57% participation rate), distributed as follows: 27 MICA I and 29 MICA II students; 24 female and 32 male students; 22 mathematics majors, 22 future mathematics teachers, and 12 enrolled in other programs. Due to the small number (N=4) of teaching assistant participants, the data was not anonymous and the analysis involved examining all responses together with a word frequency analysis using Wordle [13] of their relatively elaborate open-ended answers.

In the second part, the survey study was expanded to involve an institutional view of the nature of the MICA courses. This first includes the perceptions of Ralph, principal faculty developer of the MICA courses, as summarized from an informal interview to identify why, how, and what he came to propose as MICA I-II-III courses. In order to examine the department's evolving perspectives on the nature of the MICA courses, two viewpoints were selected. First from the department as a collective as reported in official documents, and second from one of the authors, Buteau, who has repeatedly taught MICA I since 2005. Official documents were collected for examination, including: i) the proposal document [14] for a new undergraduate program (i.e., MICA program) written by the departmental Task Force Committee in 1999-2000; ii) the Brock Calendar course descriptions since 2002 [15]; iii) the 2013-14 course outlines of the two MICA II faculty; and iv) Buteau's MICA I course outlines since 2005. Relevant excerpts were selected in all documents and chronologically summarized according to each MICA course. Our insights from our diverse roles in the MICA program complement the documentation. In Section 3, we summarize the results according to a history of the MICA courses, starting with their creation.

3. Results

3.1 Creation of the MICA I-II-III Courses: Why? How? And What?

The creation of the MICA I-II-III courses evolved from Ralph's outline and recommendations, which were used by the Brock departmental Task Force Committee [14] to develop a new teaching and learning philosophy for the Department. The new core MICA courses were designed, recommended, and first taught by Ralph. He is an exceptional individual with artistic talents (pianist, visual artist), and broad mathematical interests as demonstrated by research in financial mathematics, algebraic topology, mathematical arts, and modelling and simulation where he often assists researchers in other disciplines. Ralph is very intuitive. In his teaching, Ralph has an honest interest in his students' success in both life and mathematics. He has a genuine involvement in mathematics education as a practitioner, and from a recent pragmatic publication [16] one gains an insight into his views (of technology use in mathematics and mathematics education) and concerns.

When asked about why he came to create the MICA courses, Ralph identified two important influences: external reality and his personal experiences. First and foremost, the external reality was the decreasing number of mathematics majors at Brock, which was also a concern for many university mathematics departments at the turn of this century. As well, Ralph was aware that most of Brock's mathematics majors were not pursuing graduate studies, but entering the work force. At the time, he felt that the atmosphere and the collegiality in the Mathematics Department were such that major changes would be seriously considered. Ralph anticipated the opportunities offered by this changing environment and was given a half-year course release by the Chair to develop and recommend a reform of program(s) for mathematics majors, a task he took very seriously. These recommendations led to the creation of the sequence of core MICA I-III courses.

In the area of his personal experiences, Ralph had previously taken a three-year leave of absence (1995-98) to design and implement with a professional team, his *Journey Through Calculus* [17] software. This experience caused him to rethink ideas concerning mathematics education at the undergraduate level in a technological era. He had taught undergraduate mathematics with digital technologies since the late 1980s. In addition, for many years, he had volunteered and worked with individual mathematically talented school students of the Niagara Region. These students had completed the Ontario school mathematics curriculum well ahead of their time, and teachers turned to the Department for assistance to continue engaging them in mathematics. Ralph looked for creative projects for the students to investigate and came up with new ways to present mathematical ideas. Ralph found that these students, many of whom had a programming background, became completely immersed in their learning when they programmed an exploration of a mathematical concept or application and then communicated their understanding visually through an interface. He was pleasantly surprised by their engagement and enthusiasm, and also by the amount of time they were willing to devote to their tasks.

One of Ralph's priorities has always been to structure his teaching environments so students would have fun and be engaged when they learn to do mathematics. He found that students could have fun and be engaged in different situations, for example when they felt they were being creative, worked in self-selected projects, achieved in tasks independently, or discovered an unexpected result. When Ralph tutored a mathematically talented school student, he offered some flexibility for the individual to choose an area of mathematical interest, and he supported the student's aptitude to program as a means to creatively explore mathematical concepts and applications. These experiences, together with his research experience, contributed to an evolution of his views that programming is an integral part of numeracy.

In developing the MICA courses, Ralph aimed at re-creating the individual experience of his gifted students in a mathematics class. He wanted students to be creative and personally involved so that each student could express: "I did something related to me". He envisioned a classroom rich with discussion and interaction with classmates, faculty, and technology. Ralph envisaged a MICA terminal degree that would meet the needs of a great majority of our mathematics students who do not continue into graduate studies—a terminal degree that would provide a rich experience for exploring and using mathematics in wide-ranging work environments. The MICA program would include developing a capacity for programming and experiences in experimentation, simulation and modelling, which aligns with the five areas of university education involved in [9]. This, together with elements of the elaborated teaching philosophy, is actually how Ralph has been describing the MICA courses. As will be seen in the next Section 3.2, this was clearly reflected in the new program proposal [14], including the innovative core MICA I-II-III courses, submitted to the department in 2000 by the Task Force Committee, for which Ralph was Chair.

3.2 An Evolution of the MICA courses: a Departmental Perspective

When creating the MICA program in 1999-2000, the departmental Task Force Committee (TFC) proposed a *Teaching Philosophy* that included the statement, "*To encourage creativity, the three MICA courses will challenge students with difficult projects that require them to develop their own strategies for handling complex real world mathematics problems*." ([14, p. 16]) This evolved into a more concrete statement as found in the current MICA program description [15]:

> students [in MICA I-II courses] will confront problems from pure and applied mathematics that require experimental and heuristic approaches. In dealing with such problems, students will be expected to develop their own strategies and make their own choices about the best combination of mathematics and computing required in finding solutions.

From this, individual MICA course proposals were detailed in [14] that, in turn, led to short course description summaries in a format required by the institution, currently still in use for MICA I and MICA II courses. We provide details for each course.

The MICA I half-year course was initially proposed as "*the first in a sequence of three courses that emphasize the creative application of mathematics to solving problems using computers*." [14, p.17]. Its proposed course objectives read as:

> the primary goal of the MICA course sequence is to help students apply mathematical concepts by using computers to creatively explore solutions to mathematical problems. The second goal is to help students build a portfolio of techniques which they are confident in applying to a diverse range of mathematical problems that may or may not have exact solution. [14, p. 37]

This description is not specific to the MICA I course, but rather provides information about the overall viewpoint of the MICA courses. However, a detailed list of mathematical topics together with specific planned computer programs, and a list of minimum skills were presented. The mathematical topics are found, in part, in the official course description, unchanged since 2001: "*Exploration of ideas and problems in algebra, differential equations and dynamical systems using computers. Topics include number theory, integers mod p, roots of equations, fractals, predator-prey models and the discrete logistic equation for population growth*." [15], pointing to *experimental math*, *programming*, and *inquiry-based* areas [9]. The next Section 3.3 elaborates more of the nature of the MICA I course through the analysis of Buteau's course outlines.

The full year MICA II course was proposed by the TFC as "[*a*]*pplications of mathematics including simulation and modelling. This course is the second of the three MICA courses that focus on the connections between mathematics and technology*." [14, p.18] The course objectives provide insights into the course: "[*m*]*athematical models of all types; theory and application. Students will be expected to do at least two major projects that demonstrate creative application of the course content. One of the projects must use current data from research at the university*"[14, p.50], with a suggested textbook [18] on mathematical modelling. Similarly to the MICA I course, TFC presented a detailed description that has been summarized in the institution format as the following:

> Theory and application of mathematical models; discrete dynamical systems; time series and their application to the prediction of weather and sunspots; Markov chains; empirical models using interpolation and regression; continuous stochastic models; simulation of normal, exponential and chi-square random variables; queuing models and simulations, use of a computer algebra system. [15]

The objectives listed in one of the two MICA II teaching faculty's 2013-14 course syllabus provides additional insight into the nature of the course which can be mapped into the five areas from [9]: "*The main objective of this course is to learn basic methods of mathematical modelling and of 'experimental mathematics'. Computational and algorithmic methods and use of computers simulations will be strongly emphasized. Topics include: working with data, discrete deterministic dynamics, ...*". The other faculty's 2013-14 course syllabus lists examples of microworld-type projects that each student will create during the course; for example, "*Simulate battles between armies. (Stochastic Processes and Differential Equations)*" and "*Zoom in on bifurcations in chaotic systems. (Discrete Dynamical Systems)*" [7].

As for the full year MICA III course, it was proposed by the TFC as "[*a]dvanced applications of mathematics including modelling and simulation. This course completes the mathematics/ technology sequence begun in MICA*", with similar objectives as for MICA II, but with mention of the "*Study of advanced mathematical problems*" ([14, p.20]), and with suggested textbook [19] on advanced mathematical modeling. The MICA III official description summary, from 2001 to 2009, reflects the proposed course: "*Advanced applications of mathematics involving computers. Topics may include deterministic models; equilibrium; optimal control; probabilistic models; […]*" [15]. This original course content was, however, never taught. The content was instead modified by the two faculty who taught the course to be in line with their own mathematical interests. Students indicated their discontent with the course and questioned its relevance to their program of study. Thereafter in 2008-09, the departmental curriculum committee raised the issue of having this course, as presently taught, classified as a 'MICA' course since it was very content-driven (i.e., about Partial Differential Equations), and debated whether this course should remain a core course. The Department decided to keep the course content as it was presently taught, but to split the full-year core course into two elective one-semester courses. In other words, the course, as presently taught, was not perceived as a 'MICA' course. Indeed of the five areas in [9], the course only related to *programming* area. The description of these two elective courses can be found in [15].

3.3 Evolving Views on the Nature of the MICA I course by a Faculty Teaching the Course

I (Buteau) joined the mathematics department at Brock University in July 2004. In the following months, my colleague Ralph tutored me, through many discussions, regarding the MICA I course. In January 2005 there were two sections of the MICA course and I taught, for the first time, one section (25 students) in parallel with Ralph (30 students). Course materials were mainly prepared by Ralph, while I closely followed his teaching. In the following, I reflect on my search to understand the nature of MICA I course revealed in my course syllabi that have evolved throughout the years in line with my theoretical reflective research work on MICA with Muller and Marshall.

In January 2005, the joint course syllabus (with Ralph), stated the following course philosophy:

> This course will encourage you to be creative in using computers to explore mathematical problems and communicate mathematical ideas. The lectures will offer you interesting mathematical problems and points of view and it will be largely up to you to choose how to explore these problems and communicate what you find.

This was the only statement that provided somewhat meagre content information about the course, although students also had access to the official course description [15]. In 2009, Ralph started to teach only the MICA II course, and then I took the leadership of the MICA I course (in continuous consultation with Ralph), either by teaching all sections or co-teaching it with a sessional instructor (a MICA graduate who had completed MICA I-II-III courses). In that year, based on our work [5], I added a statement about the course learning objectives to the course philosophy:

> [T]o learn to do mathematics differently; more precisely, it is to learn to design, program, and use interactive computer environments in order to systematically investigate a self-stated conjecture, a mathematical concept, a mathematical theorem, or a real-world situation.

In 2011, I expanded on the course philosophy by stressing the different nature of this course:

> [I]t is essentially different than a traditional mathematics course, such as linear algebra or calculus, for which you could use a good textbook and learn the material by yourself.

In the same year, I supervised Marshall's Masters research project about MICA [9,11]. Also, our department undertook a mandatory program review for which program and individual course learning objectives were required. As a result of the review and guided by Marshall's work, I inserted course learning objectives, as well as selected program objectives, in the course syllabus:

> The main objective of this course is […see above] real-world situation. All activities in the course are designed around this objective. [MICA I] is an introductory course, and its main objective, which will be further elaborated in [MICA II], explicitly addresses the following abilities:
> - to program simulations and mathematical experimentation
> - to formulate conjectures from examples … etc."

This excerpt clearly points to the five areas in [9].

3.4 Teaching Assistants' Views on the Nature of the MICA Courses

In both MICA I - II courses, the teaching assistants (TAs) assist in the two-hour weekly labs, mark all EO assignments, and assist in the marking of the original projects. When asked to describe the MICA courses, their responses seem to point to a 'methodology course', for example, "*students tackling mathematical problems with programming*". Indeed, as seen in their responses' word cloud (Figure 1, right), the emphasis on 'students' is striking (something one may not expect in a content-driven mathematics course such as Calculus or Algebra), and 'Mathematics' and 'Problems' are highlighted as opposed to specific mathematical content.

Looking closely at the individual responses, all four pointed to the *programming* area, as can be seen in the following selected excerpt from one of the teaching assistants:

> Overall, these courses are meant to provide students with both the tools and the mindset to tackle a wide variety of mathematical problems efficiently, through the use of modern computer softwares.

Also most of the teaching assistants mentioned ideas and terms related to the *experimental* and *inquiry* areas. None hinted at the *simulation* area. However, when prompted through the Likert scale questions, all 'strongly agreed' or 'agreed' to relate the MICA courses to the *simulation* and *open simulation* areas. Similar results were obtained for the *experimental* and *programming* areas, while they were a little less convincing for the *inquiry-based* area. As for the question on *proof writing*, they perceived it, as expected, as not being an integral part of the MICA courses.

3.5 Students' Views on the Nature of the MICA Courses

The MICA I-II student participants (N=56) gave us their views on the nature of the MICA courses through the survey. The idea that clearly dominates their responses to the open question about how they describe the courses is 'mathematics' together with 'programming/technology/computing'. This is highlighted in the word clouds of all participants' responses (Figure 1). We found that the MICA II participants overall provided a richer description in their responses, and used terms such as 'concept', 'real', 'learn', 'use/using', 'different', 'world', and 'problems' more often (Figure 1, middle). This aligns with our view of the nature of the courses wherein MICA I students learn the 'microworld method', while MICA II students apply the method to a broad set of situations.

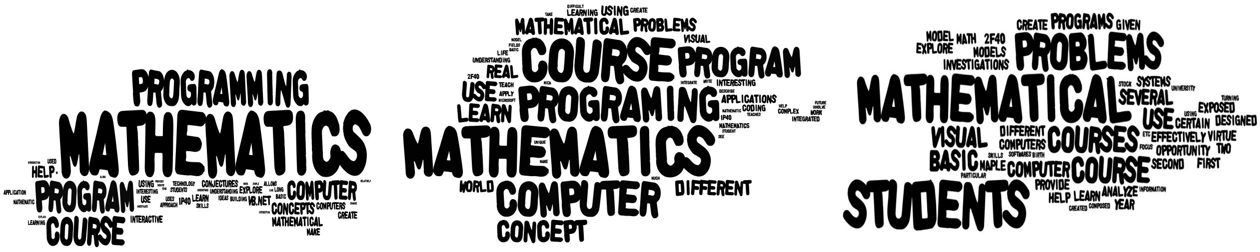

Figure 1. Word Clouds with Wordle [13] (50 words): MICA I (left), MICA II (middle), and TAs (right).

The majority of the participants' responses not surprisingly pointed to the *programming area* as illustrated in the following selected four participants' responses.

> [Student A] It is a math course that provides you the tools necessary to begin exploring mathematical concepts using technology. It is incredibly interesting and very hands-on.
>
> [Student B] The courses teach you how to use an interactive programming environment … and allows you to use it to investigate different mathematical theorems and concepts. It is very effective because it allows you to make your own program to be able to see how this concept works, and play around with it to reach a further understanding of the concept.
>
> [Student C] You create programs that use [mathematical] concepts and bring them to life to create a more concrete understanding of math and what it accomplishes.
>
> [Student D] You take real life math problems and write a program on the computer to react the said problem. You use your program to graph and simulate the problems.

A significant proportion of participants (e.g. Students A, B, and C) also specified ideas and terms that we categorize in the *experimental* and *inquiry-based* areas. Fewer participants (e.g. Student D) expressed ideas of the *open simulation* area. Because programming is part of each participant's response, there is no indication strictly to the *simulation* area. In addition, other characteristics of interests, such as interactivity (Student B), visualization (Student B), real-world problems and applications (Students C and D), and hands-on approach (Students A and C), contribute to summarize the students' views on the nature of the MICA courses.

		Gender		Course Year		Program of Study		
Area	**All**	**Male**	**Female**	**1P40**	**2F40**	**Math**	**Math Ed**	**Others**
Simulation	78.2	77.4	79.2	85.2	71.4	72.7	81	75
Open simulation	78.2	77.4	79.2	85.2	71.4	77.3	85.7	75
Programming	92.5	86.7	100	100	84.6	95	90.5	91.7
Experimental math	100	100	100	100	100	100	100	100
Inquiry learning	80.4	78.6	82.6	84.6	76	90	73.7	83.3
Proof writing	47.2	36.7	60.9	25.9	69.2	42.9	60	33.3

Table 1. Cumulative percentages ('strongly agree' and 'agree') of student participants' (N=56) views on the nature of the MICA courses.

Looking at the results of the Lykert-scale questions, overall the data suggest that students' perception is in line with the theoretical results [9] (Table 1, first column). In particular, all participants agreed on *experimental* area (100%) and most on *programming* area (93%). The *open simulation* area, which in the literature review study was identified as the closest activity to MICA EOs [9], was less convincingly perceived by students (78%). The terminology used in the question might explain the difference to the theoretical results.

Mann-Whitney tests were also conducted for each area by gender and course year, respectively, and a Kruskal-Wallis test by programs of study. No statistical difference was found for programs of study suggesting in particular that both mathematics majors and future mathematics teachers have similar views on the nature of the MICA courses. For MICA I and MICA II students, differences were identified in two areas, namely *experimental math* (p=0.001) and *proof writing* areas (p=0.000). In the former, the MICA II students more strongly identify the courses as related to experimental mathematics. As for the latter, the MICA II course can and does involve more formal proofs. In the case of gender, a statistical difference was identified in only one area, *programming* (p=0.010). In the former, the female participants all agreed identifying the *programming* area (100%) with the highest proportion to 'Strongly Agree', whereas the male participants mostly responded 'Agree', with some who actually did not agree. This will require additional examination to provide possible explanations.

4 Conclusion

In this paper, we explored how a sequence of core microworld-based courses came to life in a university mathematics department, and how students, teaching assistants, individual faculty, and the department have perceived the nature of these courses. The different perspectives on the MICA courses align in terms of the five areas [9]: starting from Ralphs' original vision to the department official documents, and extending into what students view as the nature of MICA courses. The cycle is complete: it passed from the written curriculum to the implemented curriculum, but not without difficulties as highlighted by Buteau's reflection on her search to make the nature of the MICA I course transparent and explicit to her students (and herself!). Ralph pictured student-centered MICA courses, and this was reflected in the teaching assistants' view on the courses. Also, student survey results (e.g., Figure 1) suggest the necessity of a sequence of microworld-type courses as opposed to a single one for the students to fully embrace the nature of the MICA courses, and as a consequence also for them to become proficient in the five areas as envisioned by Ralph and endorsed by a majority of faculty in the department.

In some sense, the core courses of a mathematics program at the university level articulate the department's view of numeracy, mathematical content and skills, which all its graduates take into their future employment. It is the 'what' of mathematics that all the department's graduates should experience. The core courses of the MICA program advocates a more comprehensive numeracy for its graduates than is found in traditional programs, and involves the ability to function in situations that entail, for example, simulation, modelling, and programming. This is in line with one of the recommendations by the European Mathematical Society [20] that states, "*Together with theory and experimentation, a third pillar of scientific inquiry of complex systems has emerged in the form of a combination of modeling, simulation, optimization and visualization*" (p.2). However, even though the MICA courses have remained as a core requirement for the past 12 years, there is periodic pressure to revert to more traditional content-driven courses, as was illustrated in Section 3.2 by the reversal of MICA III.

The concept of 'creativity' was omnipresent in the original MICA program proposal [14]. This is consistent with Ralph's original concept of MICA courses wherein students are engaged in creative processes; for example, in their major projects they select their own conjecture or real world problem to study, and in their communication they are assessed on their interface design. We have not examined if and how this might contribute to delineating the nature of the MICA courses and whether or not this relates to the concept of creativity as perceived in Constructionism [8].

Our study, grounded in over a decade of implementation, provides original insights on particular microworld-based core courses. Whereas the involvement of the authors as part of the MICA program provided key insights in this study, it calls for a follow-up study with external scholars to provide a more holistic view on the MICA courses, in particular exploiting their origin away from constructionism. We allege that the MICA courses, in the words of Papert, "tak[e] down walls that too often separate imagination from mathematics" and that students are "appropriating mathematics in a deeply personal way." [8, p.3]. We ask: has Ralph constructed/applied his own constructionism, and if so, does it "have any resemblance to [Papert's]?" [8, p. 1].[2]

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