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An International Fellowship Experience for Engineering Undergraduates: Improving Technical, Teamwork, and Cultural Competency*

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The opportunity to partake in an international technical experience is rare for undergraduate engineering students. While these programs are not common, this international exposure provides highly valuable educational experiences for students. This work highlights the approach, goals, outcomes, and improvements of year one in a three-year program where students applied engineering methods in a developing country to improve the design and fabrication of a low cost prosthetic limb known as the Jaipur Foot. Specifically, six students travelled to Jaipur, India to partake in not only technical work, but to also gain insight into how cultural differences affect engineering practice and to learn about the appropriate use of technology in the developing world. In summary, students developed important practical skills, but perhaps more importantly they acquired valuable communication skills and an understanding of the greater clinical impact of their work. This work supports the notion that global competency for engineers should be obtained through direct experiences in a different culture.

Keywords: Jaipur Foot; engineering education; global engineer

1. Introduction

1.1 International Engineering Undergraduate Fellowship

International engineering experiences are typically not available to pre-baccalaureate students, hence the opportunity to partake in such an endeavor is an influential event. Engineering students who participate in international study or work are exposed to the differences in engineering approaches as a result of cultural, economic, and environmental variability [1–6], and are better prepared to handle these difficult engineering problems [7–9]. These students gain invaluable experience in working with those who define and tackle problems from a different perspective and develop global and cultural competency [10–13], which have become important skills in today's ever expanding society [14, 15]. This work presents an undergraduate fellowship program which was developed to provide students with an influential international research experience during ten summer weeks.

This fellowship involved students from the United States travelling to Jaipur, India, to partake in research and design of the Jaipur Foot, a low cost lower limb prosthesis [16, 17]. The Jaipur Foot was created by Dr. P. K. Sethi in the 1970s primarily developed through trial and error. Materials used in the foot are simple and readily available in the markets of India. Each foot is produced by hand by workers who have been trained specifically in its construction. Previous attempts to mass produce

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the foot through modern manufacturing techniques were not successful, likely due to a lack of understanding of the mechanics and materials of the prosthetic device. The main technical goal of this project is to "engineer" the foot so that it can eventually be mass produced and available across the globe to people in need of an artificial limb who are not able to afford the high-cost prosthetic devices of the West.

Students were selected based on their academic record, a personal essay, recommendations from employers or faculty members, previous experience with international travel and internships, and interviews with faculty advisors. All efforts were taken to select a diverse group of students from an ethnic and gender standpoint, with the final group consistent of four males, two females, and four Caucasian, one Hispanic, and one Asian student. Each student was required to enroll in a course prior to departure which provided an introduction to cultural differences between the United States and India. While in Jaipur, students worked with both a clinician and a university engineering faculty member on the material characterization, production, and implementation of the prosthesis. The goals of this fellowship were twofold: present students from the United States with a unique international perspective on engineering design and expose them to research involving the improvement of the performance of a low-cost prosthesis.

The program, in year one of three, consisted of sending six students from the Ohio State University to India for the summer months of 2015. Students were housed in apartments located within the Santokba Durlabhji Memorial Hospital in Jaipur, Rajasthan, India, providing easy access to the Dr. P.K. Sethi Physical Medicine Centre overseen by Dr. Anil Kumar Jain. On site engineering mentoring and facilities were offered by Dr. Harlal Singh Mali at Advanced Manufacturing & Mechatronics Lab of Malaviya National Institute of Technology (MNIT) Jaipur. Students received engineering and educational support from identified faculty and graduate students at Ohio State University and Colorado State University via Skype and email. This program required students to work with mechanical engineers, biomedical engineers, civil engineers, and material scientists, thus promoting inter-specialty interactions among the science and engineering fields. In addition, students regularly met with clinicians and interacted with patients with locomotor disabilities, aiding their understanding of how differences in cultural backgrounds affect human needs. This provided students with the rare opportunity to not only apply engineering techniques in an international setting, but to directly identify how user interaction is critical to the design of a global health tool. From graduate students in mechanical engineering to doctors who fit patients with prostheses, these diverse interactions are seldom experienced on a domestic internship, much less abroad. Additionally, these interactions provided insight into the differences between American and Indian culture as they relate to health, technology, design, and social interactions.

While abroad, students were tasked with writing a journal entry three times a week in electronic format. These entries included every aspect of the experience, research difficulties and successes, cultural observations, and personal experiences. The journals provide raw insight into the diverse technical and cultural experience of the students without structured formatting. To provide a measured observation of the program, students also completed a pre-survey and post-survey, which consisted of questions pertaining to their abilities and confidence as global engineers. We aimed to support the notion that providing students with the opportunity to perform engineering research in a different culture, as opposed to simply learning through the classroom, will greatly improve their global competency.

1.2 Jaipur foot

The Jaipur Foot, first developed in the 1970s by Dr. P.K. Sethi, provides an affordable lower limb prosthesis for low income communities [16, 17]. Dr. Sethi modified the Solid Ankle Cushioned Heel (SACH) foot to meet the unique needs both physically and culturally of the Indian people [18], including increased dorsiflexion giving the amputee the ability to squat. Additionally, transverse rotation of the foot and sufficient range of inversion and eversion allows users to sit cross-legged and allow the foot to adapt to walking on uneven terrain. The foot is encased in a soft rubber to provide a waterproof, durable and cosmetically appealing product that can be used without a shoe and can be attached to any type of shank. The robustness of this prosthesis thus makes it capable of becoming a global product.

Designed to be inexpensive and made of readily available materials, the prosthesis can be made locally and caters to lower income rural amputees. Dr. Sethi did not patent the Jaipur Foot to ensure that the prosthesis would remain affordable [17]. The current design can be produced by local craftsmen in under an hour of labor and for less than 30 US dollars [17, 19]. In 1975 Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS) was registered as a Non-Governmental Organization (NGO) and today is the world's largest organization serving the disabled based in Jaipur, India. BMVSS is one of the leading distributors of the Jaipur Foot and as of March 2003 had distributed over 700,000 Jaipur feet to 20 countries [19]. Additionally, the materials of the Jaipur Foot, with the exception of an ankle bolt and two nails are biodegradable and environmentally friendly [20].

Despite all the advantages of the Jaipur foot and its heavy use in India and abroad, there are a number of limitations and areas of improvement. Compared to the weight of the native foot ($\sim$830 g [21]), the Jaipur Foot ($\sim$850 g) has a much higher perceived weight to the patient due to a lack of lower limb musculature as the foot is fitted in lower limb amputees. Another limitation of the Jaipur Foot is the lack of standardization and quality control leading to large variability in the lifespan of the prosthesis. In one study, the Jaipur Foot had a mean failure time of 22 months, some prostheses failed in as little as two months, and others had not failed at the final time point in the study at 52 months [19]. The range of durability of the foot is likely a result of the quality of material being used and manufacturing process having not been optimized or standardized. Thus, engineering techniques to evaluate failure and design improvements could vastly extend the life of the Jaipur Foot.

2. Goals

2.1 Research

From a research standpoint, the goal of this project was to provide the clinicians, scientists, and engineers in Jaipur with useful and insightful data on the mechanical behavior of the prosthesis. In a span of a few months students were tasked with assessing the current design and structure of the Jaipur Foot, developing multiple distinct projects to improve the function of the prosthesis, and completing a portion of these projects. These endeavors were also designed to be further advanced throughout the three total years of the program. In response to the weight and longevity problems facing production of the Jaipur Foot, four primary projects were developed.

Firstly, there was a need to assess the material properties of all components of the foot utilizing accepted material testing techniques. These material properties were then input into a newly developed finite element model of the Jaipur Foot. This model was created to help understand the complex loading of the full prosthesis as well as the individual components such as wood and polymers. Additionally, a more thorough patient and material database was needed to track, and analyze prosthesis failures. Finally, a low cost test fixture to assess material and whole foot structural properties was redesigned. This was critical to ensure materials that do not meet the minimum requirements are not used in the manufacturing process, as they could result in early prosthesis failure.

2.2 Education—technical

While specifics of prosthesis improvement are addressed above, an equally important goal of this work was to provide students with the ability to conduct meaningful research and develop lifelong engineering skills that are culturally responsive to local realities. The importance of this component was in students not only learning a new engineering tool—such as material testing or finite element analysis—but to identify possible areas of improvement of the prosthesis as independently as possible. It is well understood that students learn better not by being told what to do, but by investigating, researching, and critically thinking—all components of active learning [22, 23]. These technical skills coupled with independent and team-based problem solving capabilities are what make truly effective engineers [14, p. 19].

Similar to a capstone-style project, this approach of designing and implementing a project from start to finish provides a crucial design project for all engineering students [25]. However, in this case students were tasked with working on a project in a full time research setting, dissimilar to the typical capstone course which usually takes place during other coursework. As a result, students were asked to commit themselves to a single goal over a lengthy time period (10 weeks), with the hope they would become experts in their particular project.

2.3 Education—cultural

The typical undergraduate engineering education consists primarily of technical concepts as a means of preparing students for practicing engineering and design [24, 26–28]. Thus, limited cultural opportunities are available to students during their undergraduate education. However, cultural exposure creates a better rounded student and engineer, particularly as engineering becomes a more global business [4, 10]. To understand the intricacies, challenges, and strengths of collaborating, designing, and developing engineered products in a diverse setting, students should interact on a personal and professional level with new cultures. The final goal of this work was to expose these students to a culturally different setting with the same broad engineering ends: design or analyze a component or product for our functioning world.

We wanted students to be able to generally answer the following questions: What are the technical differences in engineering in India versus the United States? What are the cultural differences between India and the United States that affect engineering? In what ways can Indian culture, education, and engineering methods improve the educational experience for undergraduate students? While students were not tasked with answering these questions explicitly, these were the critical components of their experience, as the first two goals, exposure to research and technical education, were attainable without international exposure.

3. Outcomes

3.1 Survey

To directly assess perceived growth by students during the ten week fellowship in India, students were given a pre- and post-survey with twelve identical questions (among others). The questions utilized a 5-point Likert scale (Table 1) focused primarily on functioning as a globally competent engineer and asked students to rank between "strongly disagree" (1) and "strongly agree" (5) for each question. A Mann-Whitney U test was used to compare the pre- and post-response values for each question as well as all grouped responses, as these data are ordinal. The goals of this survey were to evaluate the confidence of the students prior to the program and determine if students felt the research experience facilitated significant personal growth from an international engineering standpoint.

The most clear and important finding from these surveys was that when combining all questions, an increase in agreement was found from the pre survey to the post survey ($p < 0.00005$). This shows that as a whole, students felt far more prepared and competent as a global engineer than they did before the internship. It should be noted that with a small sample size ($n = 6$), the individual question results should be viewed with skepticism, however statistical significance is included here for completeness of discussion. The questions included technical (questions 1, 2, 5, 7, 8, 9, 10, and 12), ethical (questions 3 and 4), and communication (questions 6 and 11) specific statements. These relate back to the goal of developing engineers who not only can perform technical work in a global environment, but can become dependable members or leaders of a team and can manage involvement with a wide range of cultures and circumstances.

3.2 Technical growth

Upon arrival in India and within the first week, students demonstrated eagerness to tackle each project, as evident from journal entries. While initial excitement over a new project is to be expected, the potential clinical impact coupled with enthusiasm from Indian clinicians, faculty, and graduate students certainly provided an additional amplification of energy. A representative journal entry from this phase of the project is:

> "All in all, I have a great feeling about the project and future."

Table 1. Survey questions utilized for both pre and post surveys along with the Mann-Whitney U test p-value for each question

Number	Question	p-value
1*	I am capable of working as a global technical professional.	**0.015**
2	I am aware of national and regional variations in technical standards, codes, regulations, and procedures.	0.071
3	I can make ethical and socially responsible decisions in the context of a culture divergent from my own.	0.46
4	I am familiar with cross national/cultural differences in professional ethics.	0.23
5*	I understand how my perspective as a technical professional is different from that of technical professionals in other countries and regions.	**0.014**
6	I am prepared to work with people who define and solve problems differently than I do.	0.058
7	I am aware of how culture influences technical work, including design, problem solving, analysis, and modeling.	0.10
8	I can adapt my technical knowledge and skills to different local conditions.	0.055
9	I can coordinate technical work that spans multiple countries.	0.23
10*	I can function effectively as a member of a multi-national/cultural technical team.	**0.042**
11*	I can communicate professionally in a culturally-appropriate manner.	**0.0034**
12*	I am prepared to work with technical professionals from cultures different than my own.	**<0.00005**

Students were asked to specify a level of agreement: 1—strongly disagree, 2—somewhat disagree, 3—neither agree nor disagree, 4—somewhat agree, 5—strongly agree. Bold denotes a statistical increase from pre to post survey ($p < 0.05$).

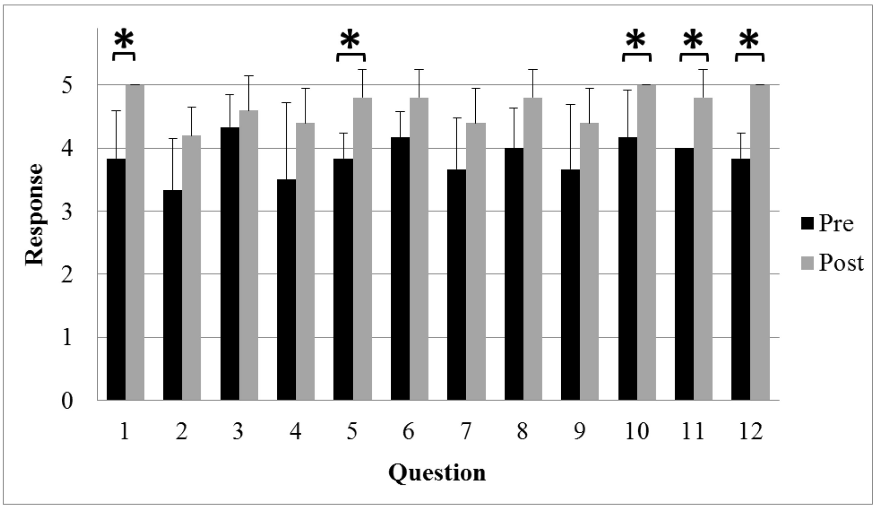

Fig. 1. Pre and post survey results where students were asked to respond to questions from Table 1 ranging from "strongly disagree" (1) to "strongly agree" (5). * Denotes a statistically significant increase from pre to post survey (Mann-Whitney U test, $p < 0.05$).

The students were tasked with developing new laboratory or computational skills within a short time period and researching their project area before diving into practical work. This type of learning stimulates a high level of growth as students were eager to absorb as much information as possible with the incentive of more hands-on work in the near future. One student wrote:

> "I have learned much and recognize that I still have much more to learn, but I am now confident that I am up for this challenge."

Following the initial phase of training and general literature search, each project became more defined. This narrowing of goals was not trivial, as students were tasked with reporting to Indian and American advisors concurrently. This process of understanding the product or problem, performing substantial background research, and outlining specific goals is crucial to sound engineering techniques. Thus, this opportunity presented to the students is similar to a problem-based learning course that undergraduates may be exposed to. However, as a full-time researcher, students were able to grasp the extent of planning and effort required for successful research. This was identified by one student as follows:

> "We have some progress and ideas of what we need to be doing next week. I feel much more engaged in the project now."

As expected, there were some technical struggles during the research. From a learning perspective, these struggles provide an important exercise for the students. The result of this work was not an exam grade or final report, but valuable information on a prosthesis with a significant clinical impact. For students to discover that research is not always a smooth endeavor shows that learning does not end once they exit the classroom. Often times in undergraduate coursework there is a known end: the answers to a problem set, a laboratory which has an expected outcome or a particular calculation during an examination. In engineering practice, however, the answer is more often not as clear. The fact is that data can be very difficult to obtain and interpret, simulations do not run as smoothly as expected, and hard work does not always yield a fantastic result, as observed by two students below:

> "This model has been much more tedious than I thought it would be."

> "It seems like we are running out of time. We are trying to squeeze in lots of material tests and design work in the last couple weeks."

Students were faced with many difficulties, but working through these challenges helped them to realize the impact their efforts could have. While technically competent engineers may be required to perform analyses, one goal of educators is to develop students who are not only scientifically competent, but also passionate about their work. In this internship, students found a chance to immerse themselves in rewarding and meaningful duties. These experiences create a true passion for science and technology and are inevitably invaluable to the personal and academic growth of students. Two examples of this dedication the students exhibited are below:

> "In the database, I have found a project that is meaningful, challenging, exciting, and fulfilling. So much so, that Friday night I stayed up until 2 AM (knowing full well I had to catch a train at 6 AM) to conquer a programming obstacle I was facing."

> "I love the feeling of satisfaction you get when you work so hard at something for so long and then finally finish it."

Upon completion of the internship, students were asked to reflect on if they experienced significant technical growth—both for themselves and the Jaipur Foot itself. Despite challenges, students felt that their efforts and progress were more than worthwhile, resulting in not only personal technical development but also in developing a foundation for future students to continue working on the project.

> "Sure, many things didn't work, but we were always able to find a way around it."
>
> "As a whole, I feel that the team has done an outstanding job in laying the groundwork for the years to come."
>
> "It's rewarding seeing the project come full circle, and to feel that we have accomplished the tasks we were given. No matter how frustrating some aspects of the project may be, I think about the potentially positive impact I can have on others that are in much less fortunate than me."

Host mentors also confirmed, through personal communication, that the students gained valuable skills throughout the summer, such as increased understanding of how to connect patient problems and engineering solutions, as the program facilitates direct student interaction with users. This is particularly impactful in the case of the Jaipur Foot, which relative to other prostheses is a simple solution to a complex problem and as such relies heavily on user feedback. Students also exceeded the professional expectations, specifically in their ability to assimilate into a new laboratory environment. Indian mentors also noted that students developed lateral thinking and troubleshooting abilities because of their adverse climate and increased responsibilities, such as maintaining communication across language barriers and managing new dietary and transportation circumstances.

3.3 Cultural growth

Interestingly, one of the most common statements by students was the difficulty of working with their peers—fellow American students—particularly in the initial phase of the internship. Faced with living in a foreign country with its own unique culture, tasked with a new research project, and working with Indian scientists, students observed changes to typical group dynamics. The difficulty of working day in and day out with a small group of people should not be lost amongst these other challenges. This is perhaps one component of the internship which was unexpected by the students, and will be closely monitored throughout the remaining two years. In fact, it may be more of a challenge as students from both the Ohio State University and Colorado State University will participate in year two of the program. This excerpt provides an excellent example of how the changes in location and culture result in changes to group dynamics:

> "My observations on the team dynamics: it's certainly no easy task to work with people, most of whom barely knew each other before, in a completely different environment both geographically and culturally, on a research project."

Throughout the summer, students were continually fascinated by the cultural differences between themselves and Indian students and mentors. This began simply as an interest in learning about a new culture, or how experiencing differences in culture gives a unique perspective in comparison to reading or being told about differences:

> "It is fun to ask them questions and learn about their culture."
>
> "I find it interesting how families still live together as they age, I understand it's part of the culture but it's different experiencing it rather than just being told about it."

This evolved throughout the program to sincere self-reflection of how their time spent in India affected their personal behavior. While students seemed initially intrigued, after a period of time the relationships they built with Indian students in particular showed them how priorities of their counterparts differed from their own. The fellowship was a life changing event for the students, and they clearly expressed this:

> "The other day I was thinking if I will be changed from this experience when I return to the states. The people here are so nice and my friends have taught me a lot about how their culture functions. I can see myself being more generous in the future because of this trip."
>
> "This has been the most eye opening experience of my life. It is amazing how the other side of the world lives."

This insight into a vastly different culture clearly plays a role in personal growth and career development. As identified above, the fulfillment experienced in a meaningful and impactful project is a powerful educational tool. This opportunity supplied these students with a personal look into how engineering can have a positive effect on a global scale. While the students developed new technical skills and provided valuable work in improving the Jaipur Foot, their own personal growth was apparent. This was closely tied to the housing location of the students within the hospital. Engineers are rarely provided the opportunity to directly identify how technology affects the health industry, particularly in a new cultural setting. Seeing patients who are fit with the prosthesis and immediately receive an increase in their quality of life was an invaluable experience for the students. The rehabilitation process for these patients was performed at the personal, family, and social level, ensuring they were capable of joining society as a healthy and contributing member. This provided perspective on how patients require more than an engineered product to address their health concerns. Students were thus able to relate to the personal side of their work, with evidence as follows:

> "With so many fortunes, I am reminded of my responsibility to use my gifts and opportunities to better the lives of others."

> "The memories that will stick with me for a lifetime are not the memories of visiting the Taj Mahal or riding an elephant. The memories that will stick with me are the memories of friendships with the MNIT students, meeting Dr. Jain's patients, and the other personal experiences I got to have here."

Finally, the students also benefitted from direct observation of differences in engineering and problem solving technique in India versus the United States. In particular, they found that Indian students seemed more personally resourceful and willing to work through issues with the materials on hand. Problem solving and creative thinking is a vital component to any successful engineer, and it is a particularly challenging ability to teach [28–30]. While problem solving in the United States may involve expanding resources, students noticed that problem solving in India involved repurposing resources or expanding the use of resources. This approach exposed students to the notion that cultural, environmental, and economic differences can drive engineering design and analysis. In summary, this new experience gave students a distinct view of how their ability to work as a team, make an impact as an engineer, and learn new approaches are influenced by culture:

> "Americans could learn a lot from people in developing countries.". . ."one of the PhD students, was resourceful and pinged a friend whose lab had an oven that worked well. Instead of complaining, she wasted little time in tapping her human capital—networking."

> "I learned a lot about how different working in India is, especially from building the fixture. Obtaining the materials I wanted to use to build the fixture was not what I expected. I thought we would go to a store and buy them easily or order them online. Instead they wanted to use things they had around the MNIT lab to build it."

4. Discussion

This fellowship gave students a rare and impactful experience and provided feedback to be used for improvements to the program in the future. These students significantly improved their global engineering capabilities, gained new appreciation for engineering in a different culture, and developed valuable technical skills. As stated, there remains two more years of the program. Year two will involve four students, two each from the Ohio State University and Colorado State University. The preparations for year two have changed significantly during the spring semester, particularly in relation to technical content. In year one, students took an independent study course the semester before they left for India. This course provided information on the culture, history, and language of India. For year two, in addition to cultural introductions, engineering techniques which are paramount to design and analysis were instructed through the course. Specifically, the course was structured into four main modules: Jaipur Foot background information, biomaterials, material property testing, and finite element analysis. The design of each module is as follows: introductory content such as literature assignments, hands on training or lecturing followed by assignment(s) on each topic in the form of written reports, oral presentations, and computational model development. These modules provide training for students in core engineering disciplines, teaching them skills required to perform the hard engineering analyses on the prosthesis. In addition to technical content, this course covered soft topics such as group dynamics, cultural differences between the United States and India, and travel logistics. This expanded preparation for the summer fellowship will allow students to fully acclimate to the lifestyle and research style in India as they will not be burdened with developing an understanding of new engineering techniques.

In the end, the goal of engineering education is to produce competent engineers from a technical and social perspective [31]. This program was invaluable to the growth of the students in these respects. Specifically, in this fellowship students developed broad and lateral critical thinking skills, which will allow them to utilize the impact of globalization. The following excerpts from student journals identify how the intersection of technical engineering and cultural influence led to their personal growth:

> "As an undergraduate research fellow, I have been humbled, inspired, and proud to be involved with something so much larger than myself or any one person."

> "The summer has left me with some new technical engineering knowledge, but more importantly, has taught me important life skills that could have only been learned through experience."

This program, only in year one of three, built the foundation for future work to improve the Jaipur Foot and did so by fostering personal, professional, and technical growth of engineering students.

5. Conclusions

This work strongly supports the use of an international fellowship research program in developing global competency of engineering undergraduate students. Furthermore, there is evidence that a program such as this facilitates a broad spectrum of growth, ranging from technical capabilities to understanding how cultural differences impact engineering design and analysis. While education in the classroom may introduce students to the importance of global competency, there is no doubt in the effectiveness of direct international experience to students' growth.

Future work could be completed to gather more in-depth reflective data on students' cultural and technical experiences. While the post surveys provide a comparative look at the development of skills throughout the program, they do not allow students to make observations and statements in their own words. Furthermore, targeted areas of cultural, economic, and environmental differences could be discussed with fellows after a time of self-reflection has passed, such as six months after returning to the United States. Finally, tracking student educational and career success and areas of research or employment could provide insight into how this international opportunity influenced their career paths.

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